LAND AIR SEA MILITARY HISTORIC

NEW

HOW IT WORKS BOOK OF

AMAZING VEHICLES

A LOOK INSIDE SOME OF THE WORLD'S MOST INCREDIBLE MACHINES

Welcome to

HOW IT WORKS BOOK OF AMAZING VEHICLES

From supersonic jets and rocket-powered planes to massive ocean liners and underwater cars, this book is packed with the most incredible machines to roam the planet. Learn about the amazing engineering behind some of the world's fastest vehicles, and how even the most powerful supercars are now eco-friendly. Discover how a new generation of luxury airliners, solar planes and submarines are changing the way we travel, research the ocean floor and observe wildlife. Learn how modern combat has been revolutionised by some truly astonishing vehicles, and delve deep into the history of engineering with the first cars and iconic planes that shaped today's transport. If you love power, speed and ground-breaking technology, engineering and aerodynamics, then you'll love the How It Works Book of Amazing Vehicles.

HOW IT WORKS BOOK OF AMAZING VEHICLES

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HOW IT WORKS

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WORLD'S FASTEST VEHICLES

Blink and you'll miss these speed machines, but what high-octane engineering is under the hood?

In 1906, on the packed sands of Ormond Beach in Florida, USA, mankind's obsession with speed shifted into an entirely new gear. Powered by kerosene-burning steam engines, the world's first racecars broke the 160-kilometre (100-mile)-per-hour mark, igniting a race for the record books – one that roars on today. In 2014, the Bloodhound SSC hopes to speed past the 1,600-kilometre (1,000-mile)-per-hour barrier, smashing the current land-speed record by nearly 400 kilometres (250 miles) per hour and reaching a velocity that could outrun a Magnum .357 bullet. The quest to build the world's fastest vehicles on land, air and sea is equal parts physics, robust materials and, to a certain extent, abject lunacy. Hundreds have lost their lives piloting home-made rocket boats and blasting experimental aircraft to the edge of space. But as long as there's a new milestone to reach – speed of sound, Mach 20, perhaps even the speed of light – our brightest scientific minds and wildest daredevils will be willing to take on the challenge.

F1 engine
Custom-built by Cosworth, this 559kW (750hp) engine will pump 800 litres of high-test peroxide oxidiser to the hybrid rocket.

Jet-powered cars

A sonic boom echoed off the stone cliffs of the Black Rock Desert in Nevada, USA, as the British-made Thrust SSC became the first land vehicle to break the sound barrier back in 1997. To qualify for a land-speed record of 1,149 kilometres (763 miles) per hour, the car needed to have four wheels and be under complete control of the driver. It also needed to withstand air pressure upwards of ten tons per square metre. To improve stability, the rocket-shaped car was equipped with twin Rolls-Royce Spey jet engines, one on each side. Each engine produced 89 kilonewtons (20,000 pounds-force) of thrust, roughly equal to 145 Formula One cars. The next-generation Bloodhound SSC – pictured here – aims to exceed 1,600 kilometres per hour (1,000 miles per hour) in 2014 with a Eurofighter Typhoon jet engine and a hybrid rocket strapped to its sleek carbon-fibre and titanium cage frame. The Bloodhound will rocket from zero to 1,690 kilometres (1,050 miles) per hour in just 40 seconds on 900-millimetre (2.9-foot) aluminium alloy wheels.

The bumps in the road

Drag is one of the greatest engineering challenges to designing a supersonic land vehicle capable of breaking speed records. Even low-flying fighter jets have only reached 1,600 kilometres (994 miles) per hour and that's without the friction of wheels on the ground. Air is much denser at ground level than at high altitude, meaning cars have to be ultra-aerodynamic (hence the rocket shape) and produce insane amounts of thrust. The Aussie Invader 5R, one of the land-speed contenders, solved this problem by sitting its driver atop what is essentially a 16-metre (52-foot) rocket engine capable of producing 276 kilonewtons (62,000 pounds) of thrust. Wheels are another huge challenge, as they need to rotate at unimaginable speeds while sticking firmly to the ground. The solution is tireless wheels machined from either titanium or aluminium, which boast a very high strength-to-weight ratio. The Aussie Invader's aluminium wheels are built for 10,000 rotations per minute. When the Thrust SSC broke the sound barrier, the shockwave 'fluidised' the sandy soil beneath the vehicle, making it difficult to steer. Next-gen rocket cars are using computer modelling to muffle those vibrations.


Some have contested the Venom GT is faster than the Veyron Super Sport overall but this is yet to be confirmed

Speed vs acceleration

In January 2013, a Hennessey Venom GT ripped down an airport runway in Texas to break the world acceleration record: 0-300km/h (186mph) in 13.63s. Acceleration is not the same as speed. Acceleration is a product of the V8 engine's torque (force) divided by the Venom GT's mass (ie a = f/m). The Venom accelerates so quickly because its lightweight 1,244kg (2,743lb) frame is cranked by 160kg/m (1,155lb/ft) of torque. The heavier Bugatti Super Sport loses to the Venom GT in a sprint, but can hold the road at higher maximum speeds.

Other speed demons… on land

Fastest wind-powered car

Ecotricity Greenbird, 203km/h (126mph)

Fastest motorcycle

Ack Attack, 606km/h (377mph)

Fastest piston engine car

Speed Demon, 743.5km/h (462mph)

Weight
1,888kg (4,162lb)

Transmission
7-speed

Price
£1.5mn ($2.5mn)

VEYRON SUPER SPORT

Top speed (restricted)
415km/h (258mph)

Acceleration
0-97km/h (60mph) in 2.5 seconds

Engine
16 cylinders, 895kW (1,200hp)

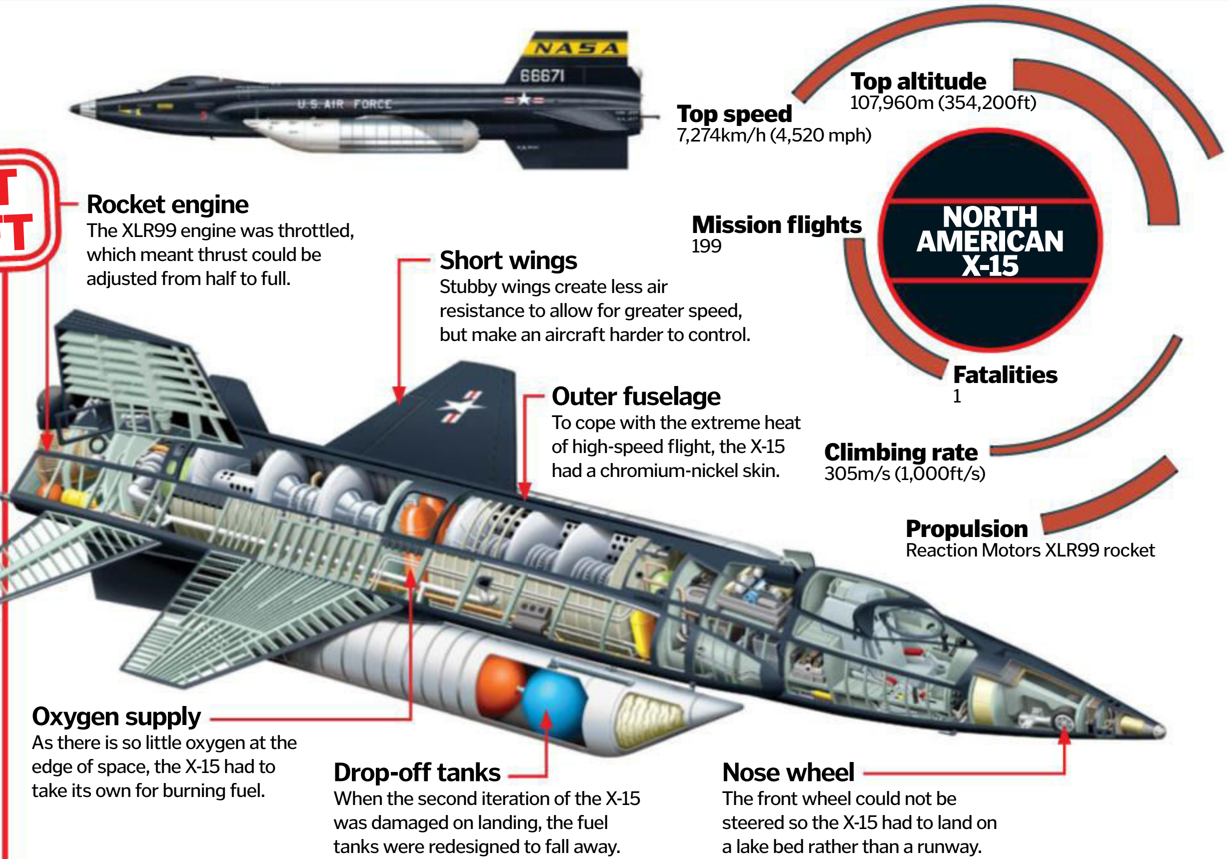
WORLD'S FASTEST PRODUCTION CAR

The first thing you notice about the Bugatti Veyron Super Sport isn't its Lamborghini good looks, but its Tyrannosaurus roar. The Bugatti's 16-cylinder engine delivers over 1,200 horsepower, ripping from 0-100 kilometres (60 miles) per hour in a staggering 2.5 seconds. The only thing preventing the Bugatti from pushing over 431 kilometres (268 miles) per hour is the rubber tyres, which would tear apart from the force. And at £26,000 ($42,000) for four tyres, it's better to be safe than sorry! To deliver that much power, the eight-litre engine gulps down fuel; at full pelt, the Bugatti would drain its entire tank in about 12 minutes.

DID YOU KNOW? *To simulate a missile flight, US Air Force researchers built a rocket sled that reached 10,325km/h (6,416mph)*

WORLD'S FASTEST MANNED AIRCRAFT

The fastest-ever manned aeroplane made its record-setting flight 47 years ago. In the early days of the Space Race, the X-15 was designed to test the limits of aeronautical engineering at the edge of space. Built like a short-winged fighter jet, the X-15 packed a rocket under its hood. To fly, it would hitch a ride on a massive B-52 up to 13,700 metres (45,000 feet). Dropped from the bomber, the X-15 lit its liquid propellant rocket capable of 500,000 horsepower. The X-15 only carried enough fuel for 83 seconds of powered flight – but it was enough to rocket its pilots into the record books.



Aerodynamic challenges

The engineering challenges for high-speed aircraft are surprisingly similar to building the world's fastest cars. Drag is still public enemy number one. As an aircraft approaches the speed of sound, the gas flowing around the plane grows more viscous, 'sticking' to the surface and altering the aerodynamic shape of the craft. Any friction with that high-velocity stream of gases will cause bone-rattling turbulence, incredible heat and shockwaves. To achieve the best aerodynamic profile, supersonic planes have swept-back wings that stay safely inside the cone of a supersonic shockwave. The F-14 fighter jet can pull its wings in tight for maximum speed and stretch them out for greater control at lower speeds. Supersonic craft are also made from lightweight materials like aluminium to further reduce drag.

Of course, you'll never reach supersonic speeds without serious engine power. X-1, the first plane to break the sound barrier in 1947, was propelled by a rocket, but modern turbojet engines like the Concorde's four Rolls-Royce turbofans, are also capable of supersonic flight. Hypersonic flight – ie greater than Mach 5 – has its own unique set of challenges because gas molecules begin to break apart and create multiple overlapping shockwaves. Experimental hypersonic designs such as the Falcon HTV look more like wingless sci-fi vehicles than traditional planes.

The HTV-2 test flight lasted about nine minutes, before heat damage forced the mission to be terminated

Other speed demons... in the air

Fastest space plane

Virgin Galactic's SpaceShipTwo, 1,752km/h (1,089mph)

Fastest jet aircraft

Blackbird SR-71, 3,185km/h+ (1,979mph+)

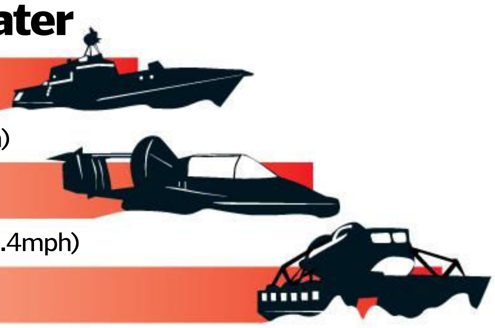
Fastest unmanned plane

Falcon HTV-2, 20,921km/h (13,000mph)

Slicing through the water

Just like air and land, the greatest obstacle to record-breaking speeds on the water is drag. Water is about 1,000 times denser than air, so the best way to increase speed on water, ironically, is to make as little contact as possible with the water itself. If you watch a speedboat race, most of the boat lifts out of the water at top speeds – an aerodynamic engineering feat called 'foiling'. The twin hulls of America's Cup catamarans lift entirely out of the water, riding only on razor-thin hydrofoil blades. The catamaran design increases overall stability without the necessity of a single hull sitting deep in the water.

Other speed demons… in water



Fastest warship
US Navy Independence, 83km/h (52mph)

Fastest hovercraft
Universal UH19P: Jenny II, 137.4km/h (85.4mph)

Fastest hydrofoil
US Navy Fresh-1, 155.6km/h (96.7mph)

Spirit of Australia

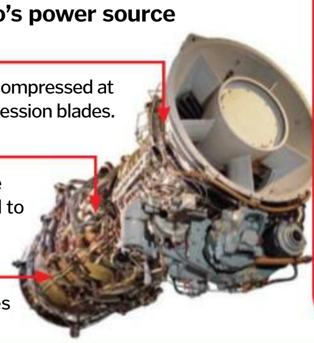
Since childhood, Australian speedboater Ken Warby dreamed of breaking the world speed record. His hero, British daredevil Donald Campbell, died trying. In the Seventies, without a sponsor, Warby built the Spirit of Australia in his Sydney backyard, buying three clunky jet engines in a RAAF surplus auction. Warby used years of speedboat experience to draft the three-point hydroplane design, in which only three parts of the underside of the boat touch the water at high speeds, greatly reducing drag. With help from a university wind tunnel and the RAAF, Warby reached a death-defying 511.1km/h (317.6mph) in 1978 – a record that still stands to this day.

WORLD'S FASTEST PASSENGER FERRY

It's one thing to see a tiny speedboat race across the ocean surface, but it's downright mind-blowing to watch a 99-metre (295-foot) ferry hit speeds of more than 50 knots (93 kilometres/58 miles per hour) while carrying up to 1,000 passengers and 150 cars. The Francisco is Australian shipmaker Incat's latest breakthrough; a twin-hulled catamaran powered by two massive turbine engines running on liquefied natural gas (LNG). The turbines force water through two enormous waterjets that propel and steer the craft, which cuts through the waves like a warm knife through butter. The Francisco will ferry passengers in style and speed from Buenos Aires in Argentina, to Montevideo in Uruguay.

LM2500 marine gas turbine

A closer look at the Francisco's power source



Compressor
Rotating fan blades draw in air that's compressed at an 18:1 ratio through a series of compression blades.

Combustor
Liquid natural gas is injected into the compressed air chamber and ignited to release tremendous energy.

Turbine
The flow of hot exhaust spins a series of turbines connected to a waterjet.

On the clock: London to New York

How long would it take the world's quickest vehicles to hop across the Atlantic at maximum speed (if there was a bridge)?

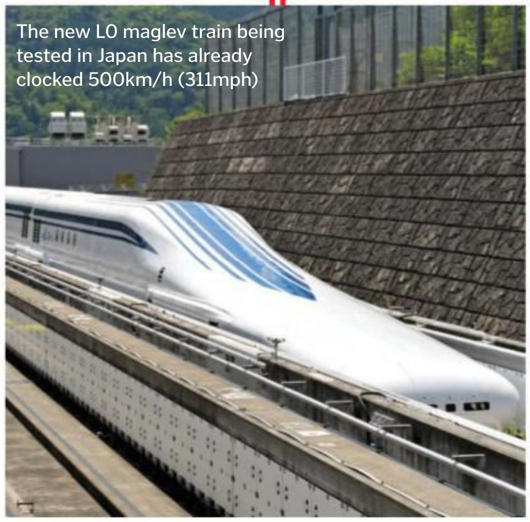
Scorpion FV101 tank
76.8 hours

VeloX3 bicycle
41.7 hours

Bugatti Veyron Super Sport
12.7 hours

Speed on the rails

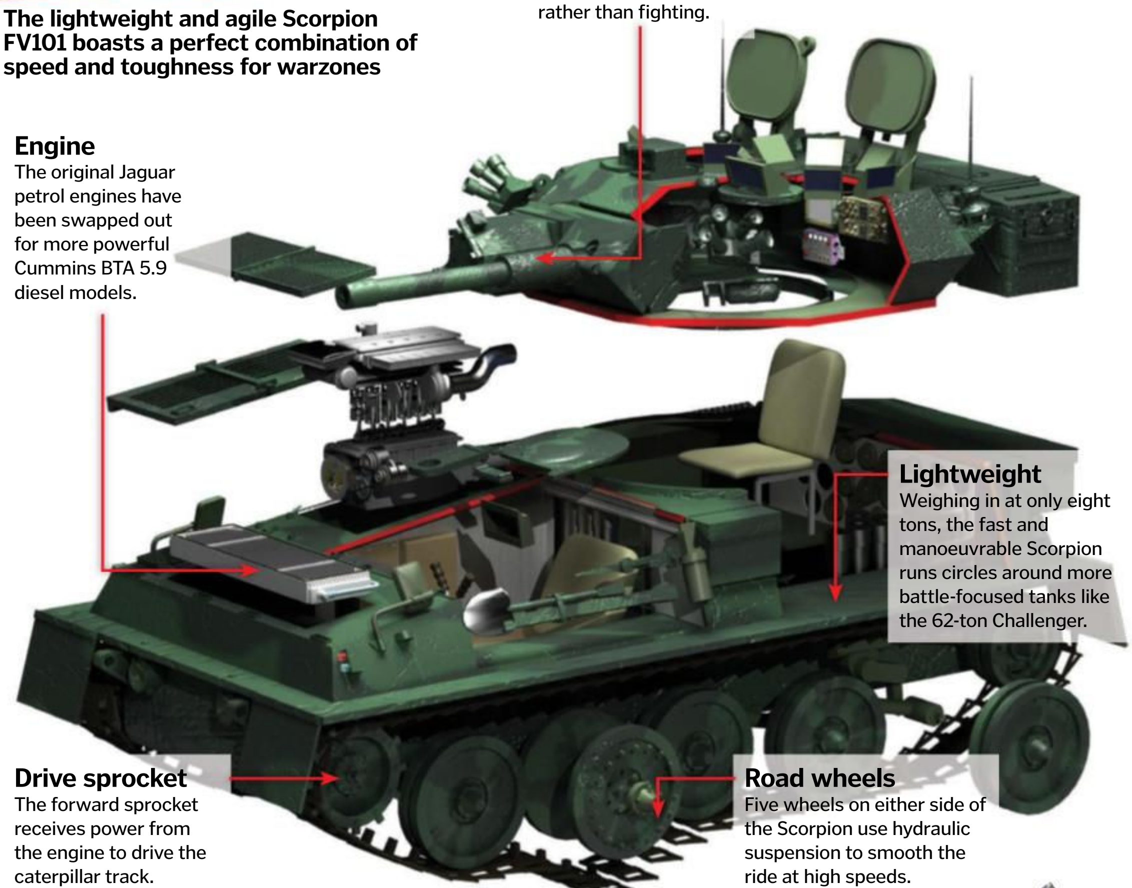
The future of high-speed trains is without a doubt magnetic. The principle of magnetic levitation (maglev) allows trains to reduce drag by floating on a one to ten-centimetre (0.4 to four-inch) cushion of air created by opposing electromagnetic fields in the track and car. The Shanghai Maglev Train in China became the first commercial maglev in 2003 and still holds the operational speed record for a commercial train: 431km/h (268mph). However, Japan is developing its own maglev line between Tokyo and Nagoya, with trials hitting the 500km/h (310mph) mark. Tech entrepreneur Elon Musk (founder of SpaceX) plans to take maglev to the next level. His Hyperloop design propels train cars through a sealed, low-pressure tube on cushions of air at speeds approaching 1,300km/h (800mph). Today, conventional high-speed lines in Spain, France, Italy, South Korea and elsewhere reach speeds exceeding 300km/h (186mph), using a combination of streamlined aerodynamics, lightweight plastics and electric-powered locomotives.



The new L0 maglev train being tested in Japan has already clocked 500km/h (311mph)

FASTEST VEHICLE ON TRACKS

The lightweight and agile Scorpion FV101 boasts a perfect combination of speed and toughness for warzones



Weaponry
The 76mm (3in) main gun isn't a tank killer, since the Scorpion was designed for recon rather than fighting.

Engine
The original Jaguar petrol engines have been swapped out for more powerful Cummins BTA 5.9 diesel models.

Lightweight
Weighing in at only eight tons, the fast and manoeuvrable Scorpion runs circles around more battle-focused tanks like the 62-ton Challenger.

Drive sprocket
The forward sprocket receives power from the engine to drive the caterpillar track.

Road wheels
Five wheels on either side of the Scorpion use hydraulic suspension to smooth the ride at high speeds.

Spirit of Australia
10.9 hours

Thrust SSC rocket car
4.5 hours

X-15 rocket plane
46 minutes

Fast and curious...

1 Milk float
By swapping the milk delivery truck's electric motor with a V8 engine, British Touring Car Championship driver Tom Onslow-Cole reached 124.8km/h (77.5mph) in the not-so-aerodynamic buggy as part of the eBay Motors Mechanics Challenge.

2 Lawnmower
Honda UK's 'Mean Mower' goes from 0-97km/h (60mph) in four seconds and claims to reach top speeds (on the track, not the lawn) of 209km/h (130mph). Makes quick work of cutting the grass, but the 1,000cc motorcycle engine might bother the neighbours!

3 Police fleet
Only in Dubai… In 2013, the city of unrepentant excess made some additions to its public safety patrol: a £275,000 ($450,000) Lamborghini Aventador and a Ferrari FF. Criminals have no chance of making a getaway!

4 Bicycle
The VeloX3, built by a team of Dutch university students, looks like an elongated egg. The recumbent bicycle is covered in a hyper-aerodynamic shell that enabled it to reach record speeds of 133.8km/h (83.1mph) in 2013.

5 Skateboard
Mischo Erban is king of the daredevil maniacs who practise the competitive sport of downhill skateboarding. Erban set a new world record in 2012, reaching 130km/h (80.7mph) on a mountain road in Québec, Canada.

HOW IT WORKS

LAND

High-speed wonders and amazing machines

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"Dragsters are the undisputed king of race cars"

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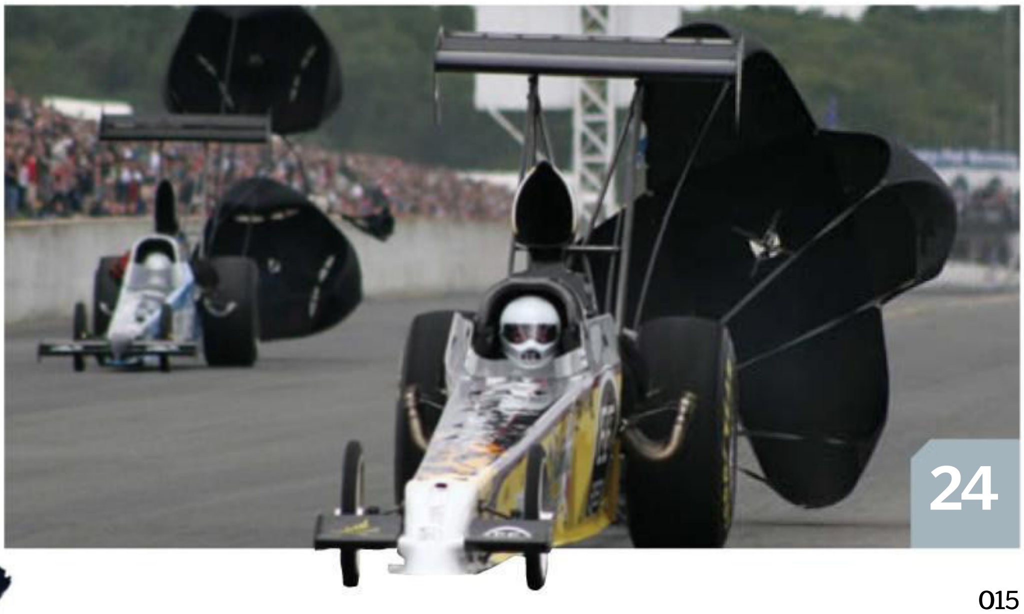

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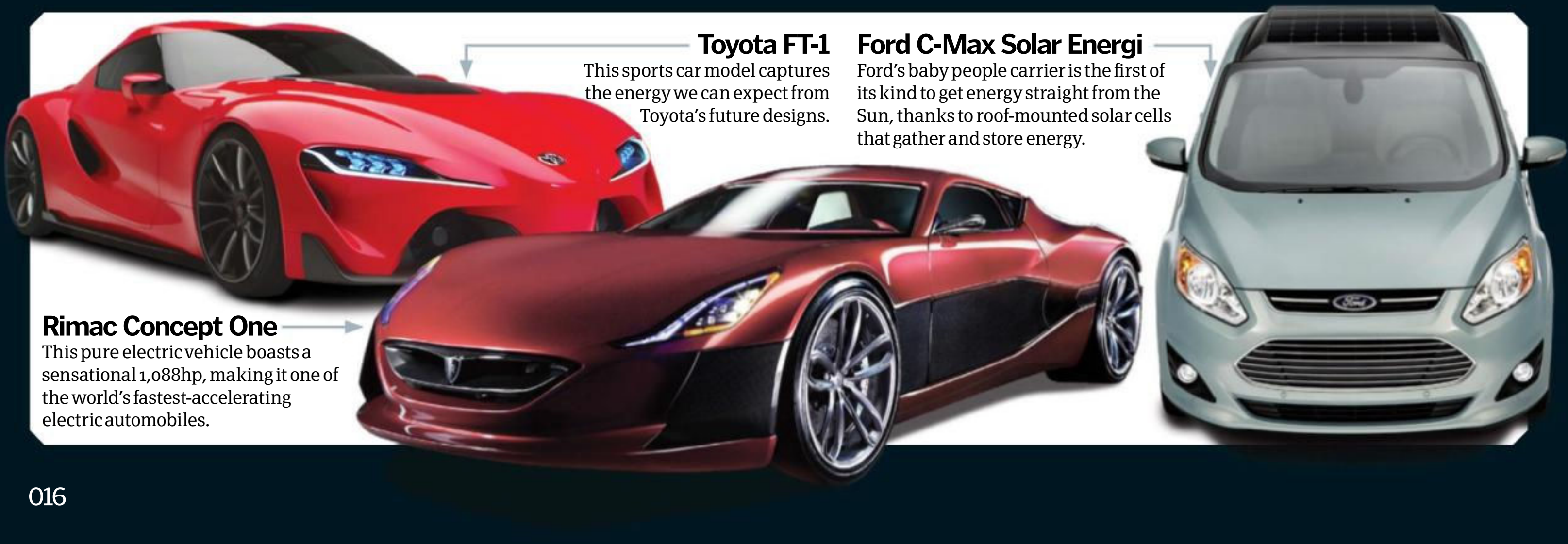
CARS OF THE FUTURE

DISCOVER THE UNBELIEVABLE NEW TECH TRANSFORMING THE AUTOMOBILE INDUSTRY



Toyota FT-1
This sports car model captures the energy we can expect from Toyota's future designs.

Ford C-Max Solar Energi
Ford's baby people carrier is the first of its kind to get energy straight from the Sun, thanks to roof-mounted solar cells that gather and store energy.

Rimac Concept One
This pure electric vehicle boasts a sensational 1,088hp, making it one of the world's fastest-accelerating electric automobiles.

The world of the motor vehicle is fast evolving. In fact, ever since the very first patent for a passenger vehicle with an internal combustion engine was filed by Karl Benz in 1886, cars have never stopped developing, often in unexpected ways.

Early breakthroughs in the industry have helped shape what we conceive a passenger vehicle to be today: just take the invention of pneumatic tyres on vehicles in 1895, the automatic gearbox in 1904 and the aerodynamics-enhancing rear spoiler in 1973 as notable cases in point.

However, in our digital age, the rate of automotive innovation has never been more rapid, with manufacturers constantly lavishing their vehicles with cool new technologies to make them faster, safer, more economical and more interactive than ever before. Much of this is down to computer technology being integrated into the vehicle.

A computerised ECU (Engine Control Unit) was first introduced on a vehicle in the 1970s to better match the amount of fuel mixing with air to ignite in the engine and power the car along the road. In the 40 years since, these have evolved enormously – despite getting smaller in size – and are now very much the all-seeing eye of a car.

A modern ECU controls various parameters on the vehicle, including different performance maps for the engine, traction control, fuel efficiency, and even when to deploy aerodynamic aids such as spoilers or to automatically turn on night-driving lights and rain wipers in some cases. With a car's ECU now taking care of more and more tasks and actions, driving a car has never been easier or safer, with the presence of advanced computers reducing the risk of human error at the wheel.

The car industry's habit of cramming technology onto a car using even smaller space simply means there's no end to the possibilities of the evolution of the motor vehicle. With this in mind, it's almost impossible for anybody to predict what vehicles will look like, sound like and even drive like by the turn of the 22nd century. However, thanks to the exciting array of technologies introduced on manufacturers' contemporary vehicles and concept cars, we can at least have some sort of idea of what's in store for cars of tomorrow.

The obvious change for vehicles of the future is a forced one: with Earth's supply of fossil fuels quickly diminishing, vehicles will no longer be able to rely on gasoline as a fuel source. Therefore, finding alternative means of power is a common goal for all manufacturers, with hybrid engines and even fully electric-powered vehicles now a common sight on the road. But fuel is just the start of this age of innovation – and the beginning of the excitement for prospective consumers…

BMW i8 concept and production vehicle

This car can be connected to your smartphone

BMW's i Remote app

This app for iOS and Android shows you current information about the status of your BMW i8, including charging status of its battery, as well as efficiency.

Concept designs

While international motor shows are famed for providing a platform for manufacturers to reveal new and updated vehicles to the public for the first time, concept cars are usually flaunted too. Often wacky and overtly outlandish in their design, concept cars are examples of one-off project ideas used to showcase the creative and technological capabilities of a manufacturer. Concept cars are largely inoperable to the capacity of a conventional road-going vehicle, and can appear incomplete, by having no interior, for example. As mere primitive creations, the vast majority of concept cars never make it to mass production, though some aspects of their design and technologies can find their way onto future iterations of mass-produced vehicles. As such, while whole concept cars shouldn't be taken too seriously by the public, their tech should: these cars are often clad with early renditions of futuristic tech that manufacturers intend to refine further for mainstream use. The Chevrolet Volt is perhaps the most famous example of this: debuting at a 2007 show as GM's first interpretation of a plug-in vehicle powered by an alternative fuel source, a much-revised Volt survived full preproduction testing and made it to showrooms worldwide by 2012.

A ride in the Toyota Fun-Vii

A concept vehicle designed to change inside and out

Connectivity features

In our contemporary age of ever-increasing interaction with digital technologies, the car industry is leading the way with clever connectivity features to enhance our entertainment and even safety in a vehicle.

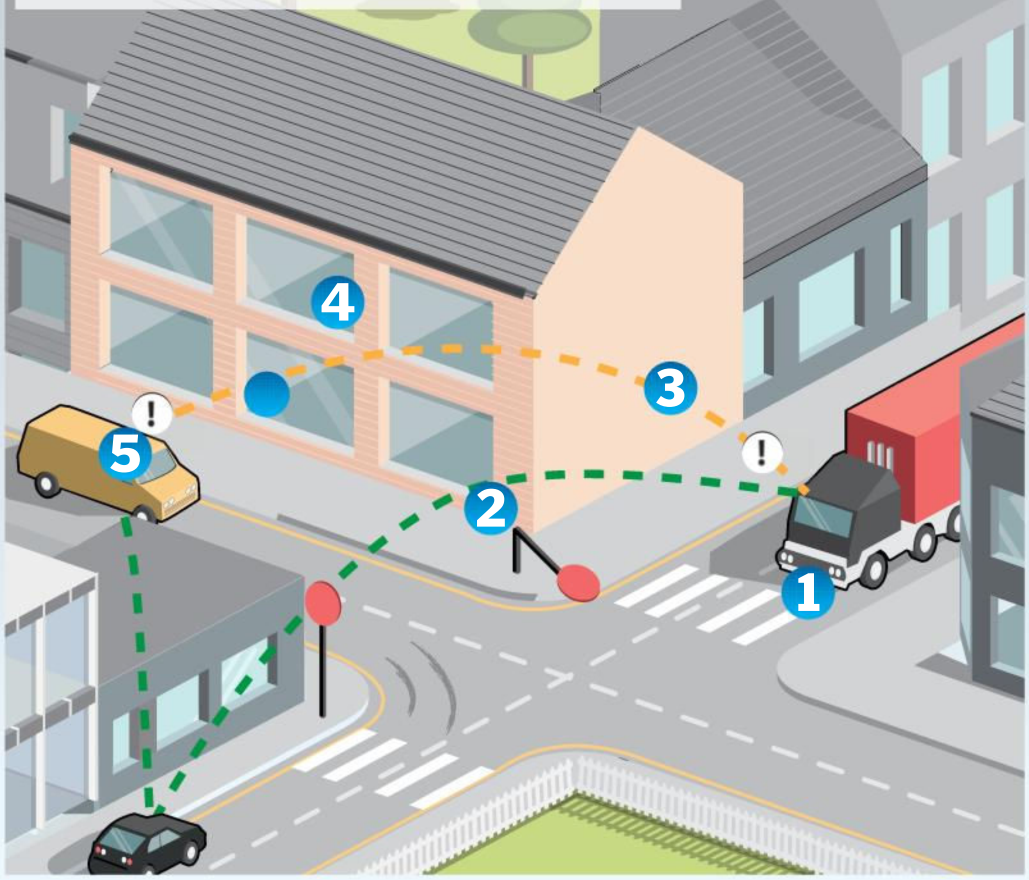
Until recently, connectivity features in a car meant being able to link up your smartphone's phone book to your on-board communication system via a Bluetooth connection, which then enabled you to make hands-free calls while on the move, but little else.

However, technological innovations now mean connectivity takes care of far more than that. Contemporary car connectivity enables you to continue to perform multiple daily tasks, usually performed by your smartphone, simply repackaging it into a safer and more user-friendly experience befitting the environment in a car. For example, now texts, tweets and Facebook messages received by your smartphone can be read aloud to the driver through the vehicle's automated voice system, and even streaming your favourite playlists through your car's speakers is the norm while actively monitoring traffic behaviour or checking the weather. Not all apps are purely for entertainment purposes either: further iterations of the connectivity technology mean you can even start your car remotely – perhaps allowing the car to warm up before you leave the house on frosty mornings – and track your vehicle via smartphone apps (ideal for parents who lend their car to their teenage children), while driver-based apps can monitor your heartbeat and stress levels while you're at the wheel.

This all contributes to a revolutionary new environment where the driver can have access to a wealth of live information while being able to constantly communicate with others and even indulge in music and podcasts without having to take their eyes off the road.

Vehicle-to-vehicle communication

This clever wireless technology could soon help reduce traffic accidents and help combat congestion



1 The scene Both vehicles in question are travelling toward an intersection, completely unaware that another vehicle is also approaching.

2 Hazard perception As the stop sign has been knocked down, a human may not realise they are required to stop at the junction, and so an accident could possibly happen.

3 Vehicle communication With this innovative new technology, each car emits a signal, which is picked up by the other vehicle, ensuring both cars' drivers are aware of each other's presence.

4 Notification If another vehicle is notified as a significant potential hazard, the driver is alerted via an automated message, making them aware of the danger.

5 Action If one vehicle gets too close to another, the brakes are automatically applied by the system.

Designing the future

Design chief Michael Mauer discusses the design process at Porsche

How long does it take to design a car?

Mauer: It varies from project to project, and there are lots of factors to consider: is it a completely new car with new technology integrated into it, or is it a revision of a current model?

Is the design process rewarding?

Mauer: Everyone who designs a car feels great responsibility, as it is the first part of a new vehicle that people see, and helps form that first impression. In the case of the 911, we know we are dealing with something very special as the car has such a great history. There's a great desire to design the perfect package each time, to optimise. It's not uncommon for designers to argue over one kilogram of weight here, or mounting something one centimetre lower there.

How important is the engineering side of new cars?

Mauer: Very important, particularly as there's an environmental aspect to be very cautious of today. This is undoubtedly the future so the challenge at Porsche is to build cars that are not only environmentally friendly, but also do not lose their performance edge.

How crucial is branding?

Mauer: Very. With Porsche, whatever we do with the 911, you have to consider how it will affect the rest of the products in terms of technology and design. Iconic cars such as the 911 must have signature elements to it, but it must also evolve to stay interesting and keep up with competitors. However, you shouldn't change for the sake of changing; you should change for the sake of getting better.

Safety tech

As well as innovative technologies helping to make our experience with cars easier and more comfortable, there is constant research and development going in to making our cars safer too.

Now a long way away from the humble air bag, car safety has developed to more intricate systems including traction control, ABS (anti-lock braking system) and even predictive emergency braking. To help with vision, cameras are replacing mirrors to reduce blind spots, and new laser headlamp technology is being piloted by German giants Audi and BMW, which offers twice the illumination range of LEDs for night driving. However, current schemes being implemented inside a vehicle for increased safety are even more finite then that: think seat belts that have sensors embedded in them to monitor breathing for signs of stress at the wheel, for example.

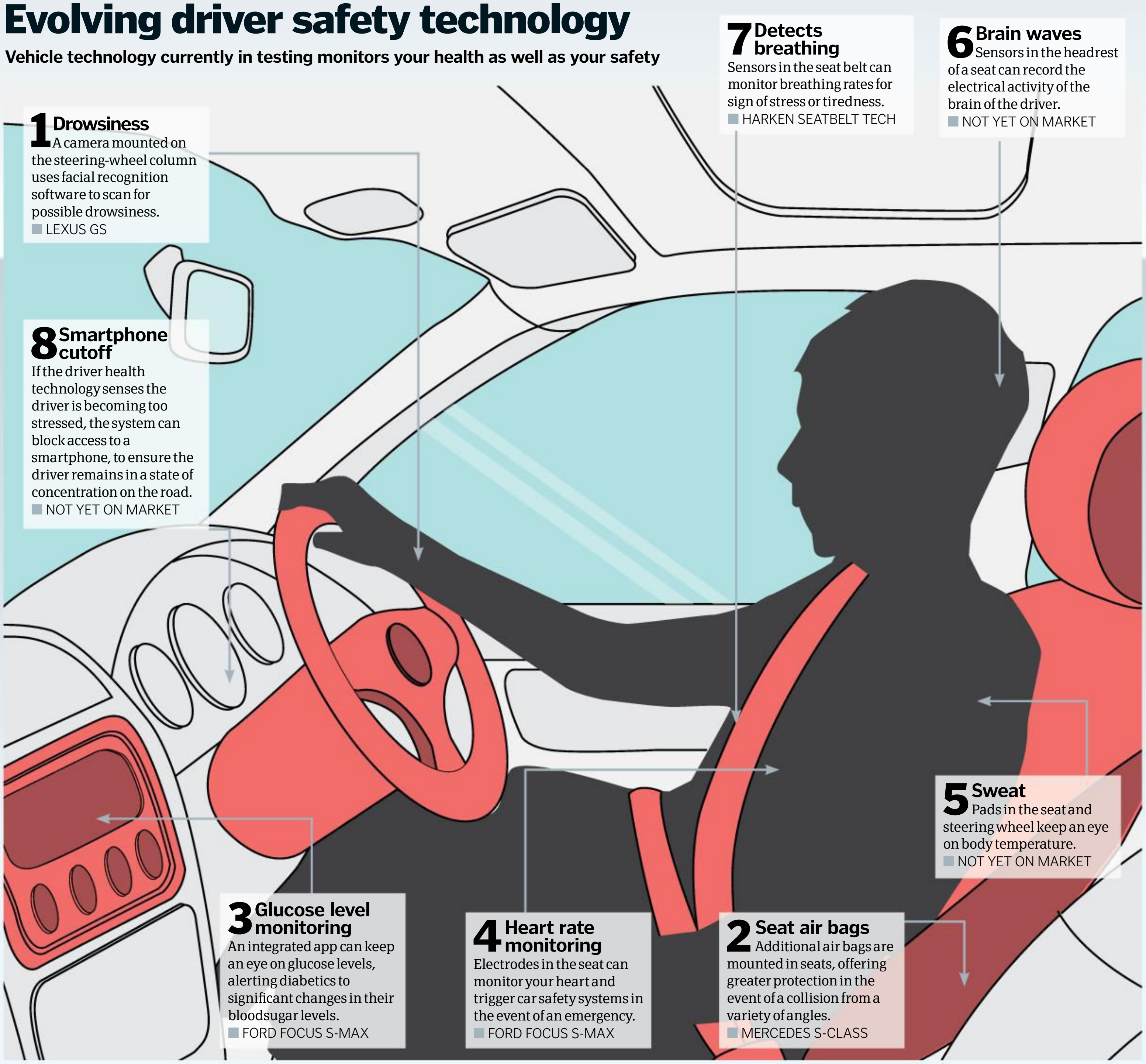
And, far from being a distant technology melded to a wild concept car, these safety features are being brought into mass production. As a case in point, the US motor company Ford has released details of active seats that can monitor your heart rate or blood sugar levels, which can then call for medical help if the readings become hazardous.

Of course, the pinnacle of car safety tech is being piloted not by a car manufacturer, but a technology giant: Google has long been experimenting with autonomous systems, even testing its very own fully autonomous vehicle on the roads of California., and now even more places around the world.

Autonomous cars use an array of car-mounted lasers, radars and cameras to successfully travel along a road, seen by some as more consistently reliable than a human that can become distracted for fatigued and make errors. All in all, there are many safety benefits to autonomous cars.

Evolving driver safety technology

Vehicle technology currently in testing monitors your health as well as your safety



Toyota FV2

The FV2 features some innovative technology

Height
When the canopy is down, the FV2 is just 99cm (39in) tall. In driving mode, it measures 178cm (70in) tall.

Interaction
The vehicle can interact with the driver by suggesting alternative routes and even destinations to match the driver's mood.

Canopy
Acts as a lid when closed, or a windshield to protect the standing driver when raised.

Steering
The FV2 is controlled in a Segway-like manner, with the driver using weight transfer to control the vehicle with ease.

Wheels
The FV2 comes with four wheels mounted in a 'diamond' layout.

Illumination
The outer shell can illuminate itself to match the perceived mood of its driver.

Power
Powered by an electric motor, though Toyota says the car can be adapted in future to suit alternative energy sources.

Power
The FV2 is currently powered by an electric motor, though Toyota says the car can be adapted in future to suit alternative energy sources.

The statistics...

Toyota FV2

Available from: Concept only

Power source: Electric

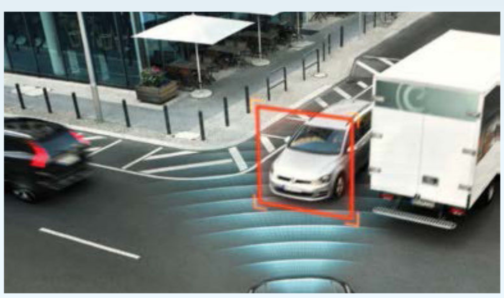
Passengers: None

Connectivity: Facial recognition offers the ability to detect mood to illuminate the vehicle.

Safety: Vehicle-to-vehicle communication.

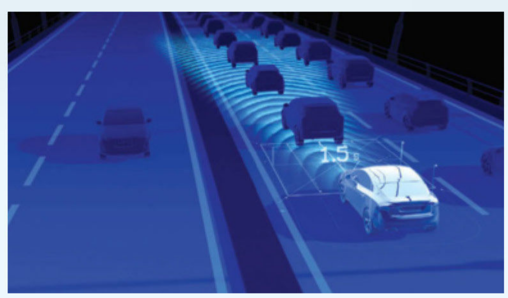
Safety at the driving wheel

Volvo XC90's new safety tech is integrated into every level of driving



AUTO BRAKE
The 2015 XC90 features automatic brake technology, which is applied when radars detect a collision is imminent. Volvo states the technology is particularly useful at busy city intersections. The car will automatically apply the brakes in order to avoid a collision, without the driver having to even initiate a stop.

AIR SUSPENSION
The new XC90 will offer air suspension as an optional extra. This is electronically controlled, meaning the driver can adjust the settings from their seat. The air suspension has a choice of five settings, allowing all occupants of the vehicle to be transported in ultimate comfort.



QUEUE ASSIST
Crawling along in traffic is an infuriating task for any driver, but Volvo's XC90 seeks to eliminate the monotony with its new Adaptive Cruise Control with Queue Assist. Using radars to slowly follow the vehicle in front, braking and steering is automatically controlled to keep directly behind the leading car.

City cars

With the planet's cities continuing to swell, space is understandably at a premium – and that includes the roads. What's more, government legislation dictates cars must meet ever-lower emissions outputs in a bid to make Earth greener, with some large cities around the world, such as London, now implementing an added tax for driving cars in 'low-emission zones'. Vehicles will therefore have to adapt to a new life in the city of the future.

Fortunately, vehicle manufacturers are already well placed to meet these new demands for the city car, with the emerging breed of small, hybrid city cars marking the start of the transition.
Not only are these cars – such as the VW up! and Skoda Citigo – small and compact to save on space, they're also extremely environmentally friendly, meaning drivers won't be blighted by increasingly stringent inner-city emissions regulations.

As cities are heavily populated and often traffic-laden, big powerful engines in cars are superfluous for such a slow-moving environment. Therefore, these new city cars are fitted with small engines, such as the 1.0-litre unit fitted to the VW up!. The advantage of this is two-fold: first, the engines will be greener, meaning they will fall on the right side of tax and emissions legislation, plus they'll use less fuel (due to the small capacity of the engine), making these vehicles very cheap to run – another reason for the sector's popularity in the overall vehicle market. And if the Toyota FV2 concept car is anything to go by, these city cars are going to get even smaller in future.

Renault Twizy
This clever city car from Renault is a compact two-seater powered only by electricity, and is on the road now.

The Renault KWID concept

The French manufacturer's new concept is as wacky in design as it is in layout

Doors
These open electrically, similar to the flashy items found on a Rolls Royce!

Interior
Inspired by a bird's nest in design, Renault says the white hue of the seats inspires connotations of lightness.

Size
The small nature of the KWID, with little overhang either side of each axle, makes it an ideal city vehicle.

Dashboard
The dashboard of the car acts as an integrated tablet device, allowing for first-hand control of the Flying Companion and other connectivity features.

'Flying Companion'
The KWID comes with a remote-controlled drone that can be sent into the air to monitor traffic or take pictures.

Engine
The KWID is powered by a turbocharged 1.2-litre engine, keeping emissions down but power up.

Seating
This five-seater breaks convention by having a three-person bench in front of two seats.

Driver position
The steering wheel is mounted in the middle of the dashboard, so the driver sits in the middle of the front bench rather than the right or left.

Alternative energy
The KWID can switch to pure electric energy if the technology becomes mainstream, with space set aside to add batteries to the car in the future.

The statistics...

Renault KWID

Available from: Concept only

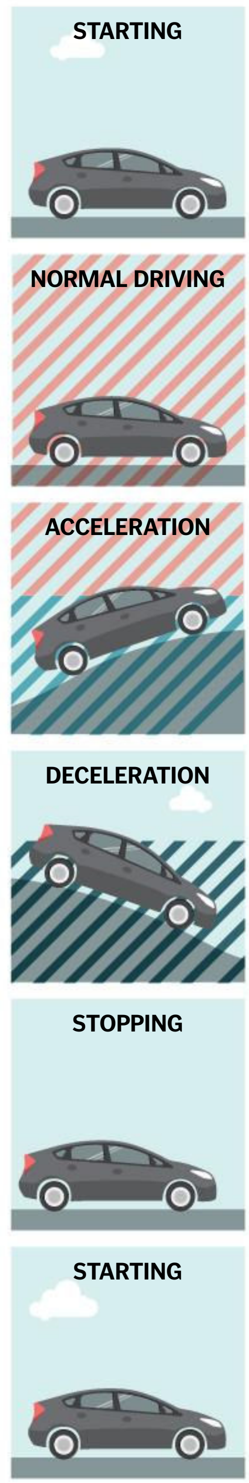
Power source: Turbocharged gasoline engine; can adapt to electric power in future.

Passengers: Five

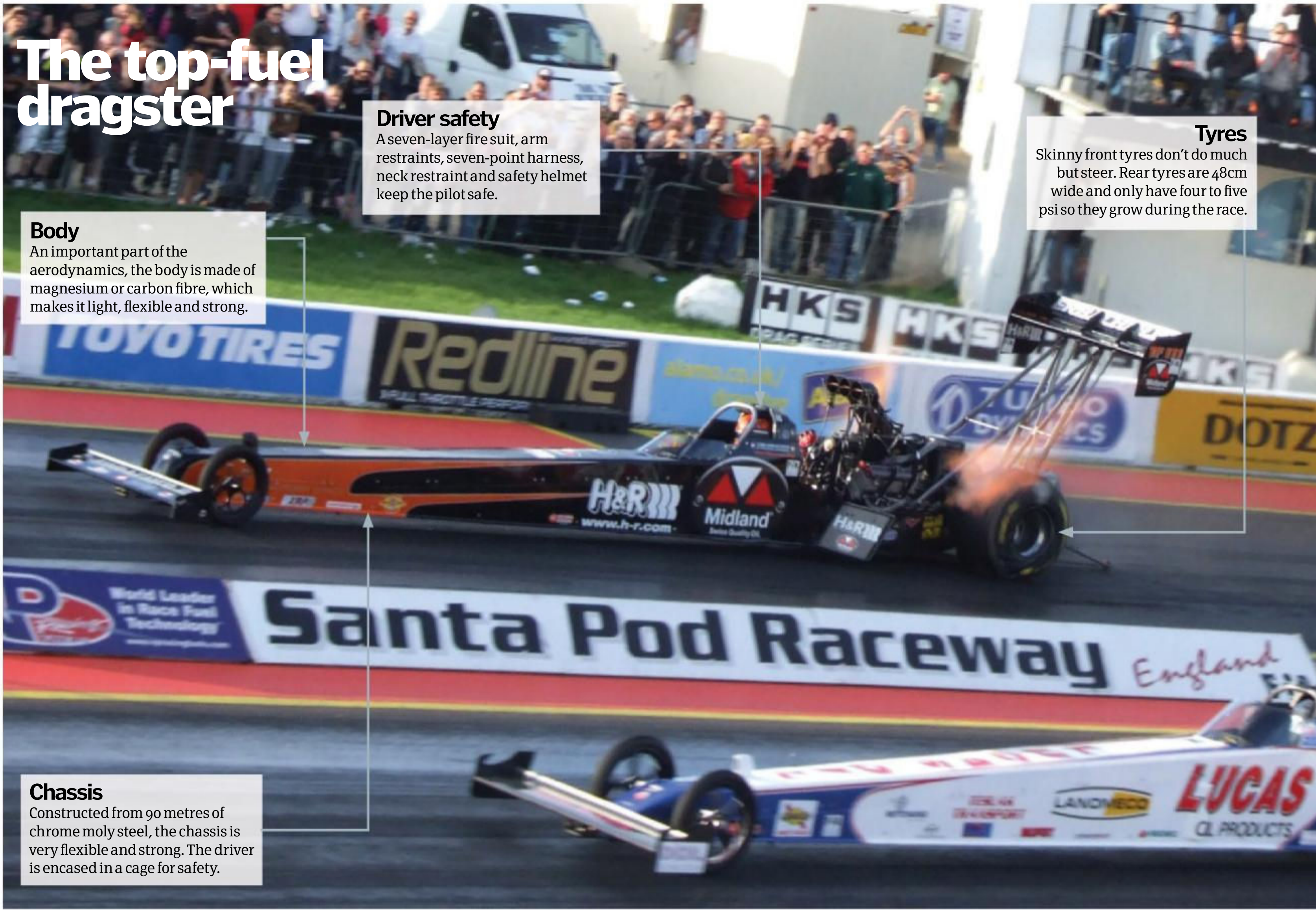
Connectivity: 'Flying Companion' drone controlled from dash-mounted tablet.

Safety: Central-mounted steering wheel, so neither left nor right-hand drive

HOW HYBRIDS WORK



ELECTRIC MOTOR IN USE THROUGHOUT
PETROL ENGINE USED
BATTERY POWER USED
BATTERY RECHARGING



Dragsters

8,000bhp, 0-300mph in four seconds, we take a look at the kings of the sprint

The most exhilarating, ferocious and spectacular vehicles on the planet, top-fuel dragsters really are the king of all race cars. Drag racing itself is a standing-start acceleration contest between two vehicles over a measured quarter-mile track.

The most striking thing about the sport's quickest car – the top fuel dragster – is its massive ten-metre length. They are designed for perfect weight transfer when the driver hits the throttle. Static, 66 per cent of the weight is on the rear and 34 per cent on the front. Within 0.1 of a second as the car launches, 98 per cent is on the rear. This is perfect weight transfer, which means more grip and traction, no wasted motion and a 0-100mph time of 0.8 seconds. The acceleration is so great that it only takes twice its length in distance to get there. The 300mph mark is reached in just four seconds with the average quarter-mile run finishing in around 4.6 seconds at over 320mph. Then the driver will use twin parachutes to slow down from these speeds at the finish line.

The racetrack is specially prepared with rubber and glue, and rear tyres are basically massive slicks that need to be warmed by spinning them in a 'burn out'. The vehicles are powered by V8 engines that run on Nitromethane fuel. This is the explosive stuff that is four times more powerful than regular petrol. The cars are hand-built from chrome moly steel and have huge aerofoils or 'wings' both front and rear that produce tons of downforce to keep it stuck to the ground.

Sitting behind the starting line, the car is 'fired up' by using an external starter motor. The driver rolls forwards and spins the rear tyres to heat them for the race. This leaves a fresh track of rubber from which to 'launch'. The crew put the car exactly in the new tracks, and then the driver concentrates on the 'Christmas tree' starting light system.

As the driver hits the throttle on the green, they experience up to seven Gs of acceleration. The car accelerates all the way through the quarter-mile racetrack until at the finish line, with both parachutes deployed the driver will

100m sprinter 43.18 seconds at 18mph

Scooter 15.9 seconds at 83mph

Mini 15.44 seconds at 92mph

Bugatti Veyron 10.8 seconds at 140mph

Top fuel dragster 4.6 seconds at 320mph

Timeline of a drag race

A lot can happen in just 4.6 seconds

0-1 seconds

Launch

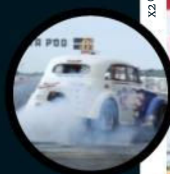
Throttle mashed, rear tyres squat, front wheels lift, 100mph in 0.8s, clutch slipping seven Gs.

1-2 seconds

Hunch

Tyres growing, front wheels settle down, clutch locks up, now doing 180mph, five Gs.

2-3 seconds



Starting to fly

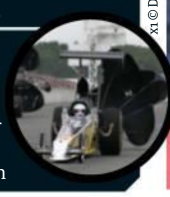
Tyres almost fully grown, clutch now almost 'locked', one gallon of fuel a second is used, now up to 250mph, four Gs, aerofoils (wings) producing eight tons of downforce.

3-4 seconds

At full tilt

Tyres at maximum growth, clutch locked 1-1 with the engine, now up to 300mph and settled to three Gs.

4.6-5 seconds



Ouch

320mph, moving at 120 metres per second, parachutes out, minus seven Gs and 100mph deceleration

x2 © Sharon Dawes

x1 © Dave Jones, 2009

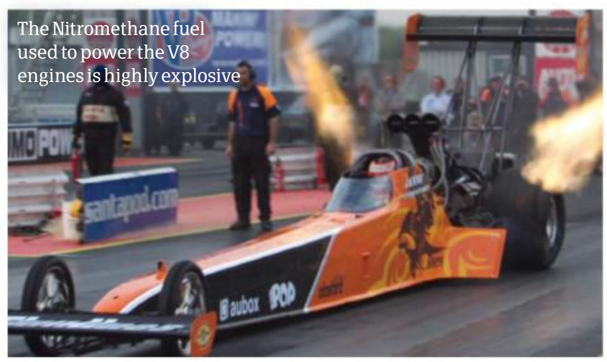
Christmas tree

The starting system at a drag strip

experience seven negative Gs. The drivers are encased in a steel cage, with full fire safety protection.

Because it is so powerful, the engine takes a hammering every run. This means the crew have to take the whole thing apart, check for breakages and replace anything and rebuild it normally within one and a half hours for the next round of racing.

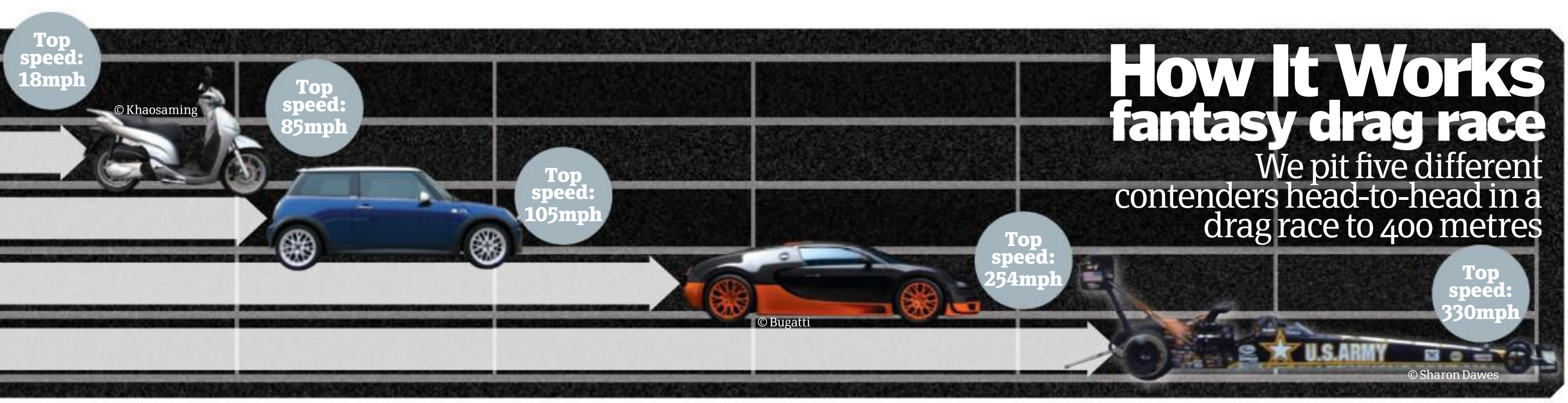
Drag racing is a dangerous yet thrilling extreme sport



The Nitromethane fuel used to power the V8 engines is highly explosive

How It Works fantasy drag race

We pit five different contenders head-to-head in a drag race to 400 metres



Muscle cars evolved

We explore how the latest generation of North American muscle cars is obliterating years of European engineering with a bevy of sophisticated technology

For decades, despite their prestige and beauty, North American muscle cars were dismissed by automotive pundits as nothing more than straight-line dragsters. Machines that, while delivering bucketloads of raw power, time and again fell short of the all-round performance and engineering delivered by their European counterparts. Critics would joke to boredom about the inability to turn, brake or even survive for more than a few hours in Mustangs and the like, ignoring these vehicles' craft and many strengths.

Of course, there was an element of truth to the critics' claims – turning certainly hasn't been a strong capability of muscle cars in the past – however, as of 2012, things have radically changed. A new generation of muscle cars is smashing through the walls of European supercar dealerships and then leaving their current offerings in the dust, out-accelerating, out-manoeuvring and out-gunning prestige marques in every way that matters. Far from dumb brutes, today's muscle cars are some of the most technologically refined and advanced vehicles on the planet, not just giving big players like Ferraris, Porsches and Jaguars a run for their money, but leaving them in the scorched remains of a horizon-busting burnout.

Letting this new breed of automotive beast take the spotlight in this feature, we examine three of the most iconic muscle cars currently in production. We reveal their power, performance and – most importantly of all – the technology that's transforming them into some of the best cars on Earth. So you might want to strap yourself in, as you're in store for one heck of a wild ride…

Be afraid, be very afraid… The Shelby GT500 can even outpace a Ferrari California

Shelby GT500

The ultimate Mustang, the Shelby GT500 is obscenely fast and likely to give you an adrenaline rush like no other

Let's get the unsurprising facts out of the way first. The 2013 Shelby GT500 is equipped with the most powerful production V8 engine in the world and also the most efficient one in America, producing more than 485 kilowatts (650 brake horsepower). These two achievements are made possible by an all-aluminium block, 2.3-litre (0.6-gallon) supercharger, upgraded cooling system, larger engine fan, redesigned air cooler, higher-flow intercooler pump and a 36 per cent increase in the capacity of the intercooler's heat exchanger. That's impressive – 325 kilometres (202 miles) per hour impressive – but not something that is particularly shocking for arguably one of the most iconic muscle cars ever.

What *is* surprising is the way the GT500 converts that immense power into refined performance. After all, strapping 650 horses to a chassis raises myriad problems, none more so than that of ensuring solid traction and handling. The GT500 deals with these issues through a launch control system – an electronic configurator that enables drivers to set specific rpm launch points – along with a Torsen limited-slip differential and AdvanceTrac steering-assist. Combined, all this advanced tech allows this modern Mustang to maximise the amount of raw power put down, as well as control it while cornering.

Further, the Shelby GT500 complements its all-round performance by the inclusion of a top-of-the-range braking system. Accompanying the 48-centimetre (19-inch) front and 51-centimetre (20-inch) rear forged-aluminium alloys is a new Brembo-made system of rotors and callipers (with six pistons at the front), as well as a series of composite brake pads oriented towards sharp acceleration and deceleration manoeuvres. These, along with a four-profile traction control setup plus an SVT-designed set of Bilstein shock absorbers, ensure excellent handling on the road as well as on the track.

Engine
The supercharged, intercooled 5.8l (1.5ga), 32-valve V8 petrol engine outputs 485kW (650bhp), which enables the GT500 to accelerate from 0-97km/h (0-60mph) in just 3.5 seconds.

Brakes
35.6cm (14in) Brembo vented rotors with six-piston callipers in the front and 30cm (11.8in) vented rotors with a single-piston calliper at the rear help the GT500 stop rapidly.

Electronics
A four-profile traction control setup along with a Bilstein electronically adjustable damper system delivers excellent handling on both road and track.

The statistics…

Shelby GT500

Length: 4,780mm (188.2in)
Height: 1,400mm (55.1in)
Weight: 1,746kg (3,850lb)
Engine: 5.8l (1.5ga) V8
Transmission: Tremec six-speed manual
0-100km/h (0-62mph): 3.5sec
Power: 485kW (650bhp)
Efficiency: 8.5km/l (24mpg)

Chevrolet Camaro

The Camaro specialises in pouncing on European supercars and taking out their performance stats with lethal efficiency

As you'd expect from one of the biggest names in muscle car production, the Chevrolet Camaro is pretty fast. Achieving 0-97 kilometres (0-60 miles) per hour in 5.2 seconds, it could keep up with a Jaguar XK with ease, but unlike Camaros of old, today's models boast tech that make it not just a pacy machine, but one that can handle most terrains – and without consuming vast quantities of hydrocarbons to boot.

Critical to this is the StabiliTrak electronic control system. This consists of four speed sensors on each wheel, a rotation rate sensor on the wheelbase, a steering angle sensor on the steering wheel, a brake-operating hydraulic unit and a master control unit in the engine bay. Combined, these components monitor every manoeuvre and make instant adjustments to maintain maximum traction.

How this works is best explained with a theoretical manoeuvre. If a driver has to corner sharply to the left and then immediately right at high speed, the steering angle sensor detects the initial input and transmits it to the master control unit. At the same time, the Camaro's rotation rate sensor – which measures the car's lateral speed and rotation around its centre line – determines its projected potential for straight-line drift and also communicates this to the control unit. The brains of the system act upon the feedback, adjusting the car's rear-left hydraulic brake, slowing its rotation and aiding a smooth cornering manoeuvre. To avoid oversteer, when the car's steering wheel is turned back to the right to take the next bend, StabiliTrak gauges the rotation speed of the front-left wheel and repeats the process, this time reducing the right-hand turning force and preventing the vehicle's back-end from spinning out.

The other notable engineering feat on the reborn Camaro is GM's Active Fuel Management (AFM) technology. This electronic system automatically deactivates four out of the vehicle's eight cylinders when cruising at speed to conserve fuel and boost miles-per-gallon economy. This is a lot more complex than it sounds, as the engine control module (ECM) has to automatically reprogram the cylinders' firing pattern each time a deactivation takes place.

For example, if a Camaro is sustaining a cruise speed with light throttle response, the ECM will – ideally – deactivate cylinders one and seven on the engine's left bank, plus four and six on the right, creating a four-cylinder firing order of eight, two, five and three. However, if cylinder one is undertaking a combustion event when the AFM is called on, then the ECM automatically detects this and, rather than forcing deactivation, bumps the deactivation on to the next cylinder (ie cylinder eight), which in turn rearranges the deactivation pattern for optimum efficiency.

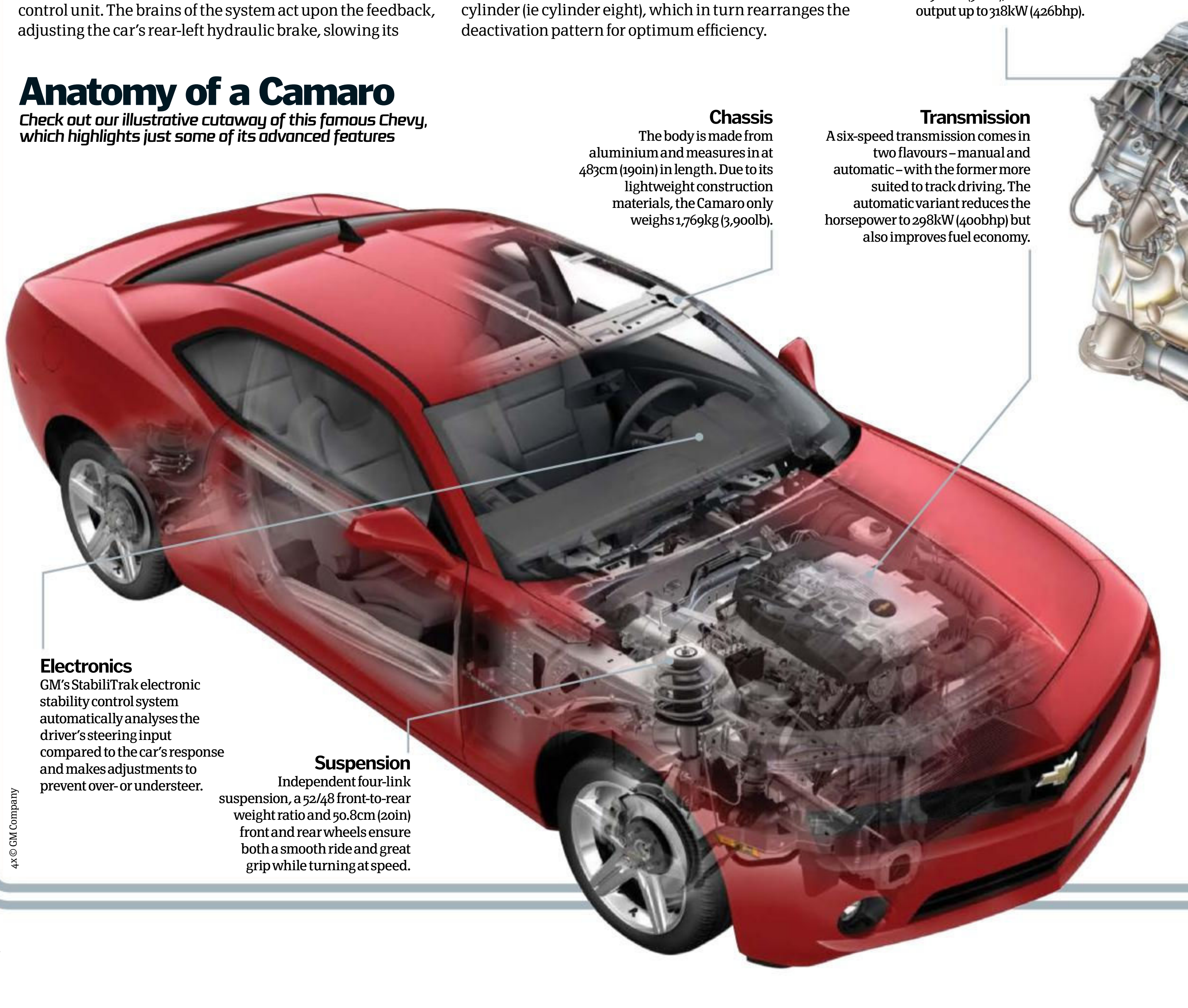
The statistics...

Chevrolet Camaro

Length: 4,837mm (190.4in)
Height: 1,360mm (53.5in)
Weight: 1,769kg (3,900lb)
Engine: 6.2l (1.6ga) V8
Transmission: Six-speed manual
0-97km/h (0-60mph): 5.2sec
Power: 318kW (426bhp)
Efficiency: 9.77km/l (27.6mpg)

Anatomy of a Camaro

Check out our illustrative cutaway of this famous Chevy, which highlights just some of its advanced features



Engine
The 6.2l (1.6ga) V8 engine in the Camaro is quite something. Thanks to improvements such as an enlarged cylinder bore of 10.3cm (4in) and a stroke length of 9.2cm (3.6in), the block can output up to 318kW (426bhp).

Chassis
The body is made from aluminium and measures in at 483cm (190in) in length. Due to its lightweight construction materials, the Camaro only weighs 1,769kg (3,900lb).

Transmission
A six-speed transmission comes in two flavours – manual and automatic – with the former more suited to track driving. The automatic variant reduces the horsepower to 298kW (400bhp) but also improves fuel economy.

Electronics
GM's StabiliTrak electronic stability control system automatically analyses the driver's steering input compared to the car's response and makes adjustments to prevent over- or understeer.

Suspension
Independent four-link suspension, a 52/48 front-to-rear weight ratio and 50.8cm (20in) front and rear wheels ensure both a smooth ride and great grip while turning at speed.

The Camaro hits 97km/h (60mph) in an impressive 5.2 seconds

Dodge Challenger

The Dodge SRT8 sends out a challenge not just to other muscle cars, but any vehicle that dares to take it on

Where the new Shelby GT500 and Chevrolet Camaro partner their raw power with unseen and subtle advanced technologies, the Dodge Challenger struggles more to shake off its muscle car heritage than perhaps any other.

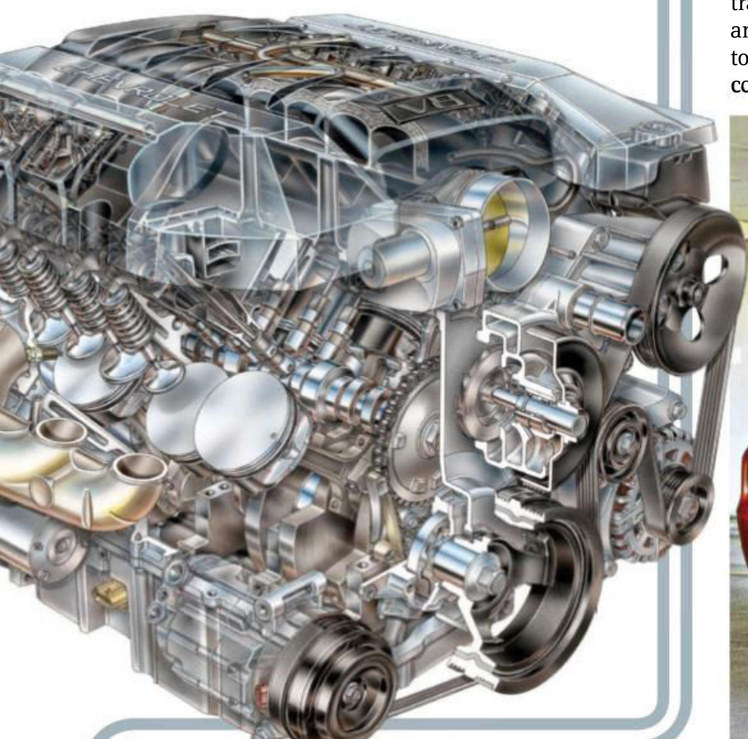
Indeed, aside from the cart-breaking frenzy of the giant 6.4-litre (1.7-gallon) V8 engine – a block capable of outputting more torque than a Lamborghini Gallardo – the on-road stability granted by automatic electronic rain brakes, tyre pressure monitors, antilock vented brake discs and a steering assist computer is second to none. With added responsiveness delivered by independent front and multi-link rear suspension, the Challenger specialises in providing the user with critical information to help maximise the driving experience.

Central to this is the Challenger's Electronic Vehicle Information Center (EVIC). The EVIC consists of a trip computer, G-force indicator, two speed timers, 0.2-kilometre (eighth-mile) and 0.4-kilometre (quarter-mile) automatic log, and a multimedia information centre. This, partnered with Dodge's trapezoidal systems gauges – which includes a digital compass and temperature sensor, allows for the vehicle's performance to be closely monitored and then tailored dependent on driving conditions, the terrain and the driver's skill level.

The statistics...

Dodge Challenger SRT8

Length: 5,021mm (197.7in)
Height: 1,450mm (57.1in)
Weight: 1,886kg (4,160lb)
Engine: 6.4l (1.7ga) V8 SRT HEMI
Transmission: Six-speed manual
0-97km/h (0-60mph): 3.9sec
Power: 350kW (470bhp)
Efficiency: 8.14km/l (23mpg)



The Challenger comes with a G-force indicator as well as 0-97km/h (0-60mph) and 97-0km/h (60-0mph) timers

2x © Death Writer

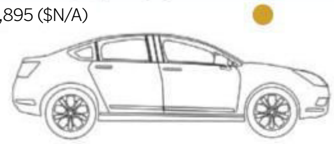
Flexing their muscles...

HIW pits the Shelby GT500 against a Citroën C5 and Ferrari California to see which car makes the best all-round ride

Key: 1st, 2nd, 3rd

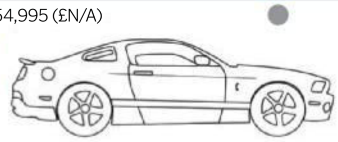
Citroën C5

Weight: 1,670kg (3,682lb)	1st
Efficiency: 14.9km/l (42.2mpg)	1st
Engine size: 1.6l (0.4ga)	3rd
Power: 115kW (154bhp)	3rd
Max torque: 240Nm (177lbf/ft)	3rd
0-100km/h (0-62mph): 8.2sec	3rd
Top speed: 209km/h (130mph)	3rd
Cost: £19,895 ($N/A)	1st



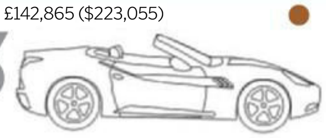
Shelby GT500

Weight: 1,746kg (3,850lb)	3rd
Efficiency: 8.5km/l (24mpg)	2nd
Engine size: 5.8l (1.5ga)	1st
Power: 410kW (650bhp)	1st
Max torque: 600Nm (443lbf/ft)	1st
0-100km/h (0-62mph): 3.5sec	1st
Top speed: 325km/h (202mph)	1st
Cost: $54,995 (£N/A)	2nd



Ferrari California

Weight: 1,731kg (3,817lb)	2nd
Efficiency: 6.7km/l (19mpg)	3rd
Engine size: 4.2l (1.1ga)	2nd
Power: 360kW (483bhp)	2nd
Max torque: 505Nm (372lbf/ft)	2nd
0-100km/h (0-62mph): 3.8sec	2nd
Top speed: 312km/h (194mph)	2nd
Cost: £142,865 ($223,055)	3rd



REAL-LIFE BOND CARS

REVEALED: THE GADGET-PACKED, BULLETPROOF RIDES THAT SHIELD SPIES, ROYALS AND WORLD LEADERS

Flamethrowers
The only DB10 gadget revealed so far is a set of powerful flamethrowers that shoot fire from the rear of the car.

"Aston Martin worked closely with the movie's director to design the DB10"

Manual transmission
Bond will have to shift gear himself as the car features a six-speed manual transmission unit instead of an automatic gearbox.

Not for sale

Aston Martin have only made ten of the cars, and all of them have been used on the set of the movie. Seven were written off in destructive stunts!

007's new wheels

Meet Bond's sleek and speedy co-star from the latest movie, *Spectre*

Whether he's chasing down villains or wooing Bond girls, 007's most important gadget is always his car. The new movie is no exception, and will pit the Aston Martin DB10 against the powerful Jaguar C-X75 concept car in an extreme cat-and-mouse chase around the streets of Rome. Aston Martin worked closely with the movie's director Sam Mendes to design Bond's bespoke DB10, but has adopted MI6-level secrecy about the car's features. In the movie trailer, Bond's gadget inventor, Q, says that the two-door coupe has "a few little tricks up her sleeve", but only a few of these have been revealed. Here's what we know so far…

James Bond's high-octane adventures showcase cutting-edge car tech

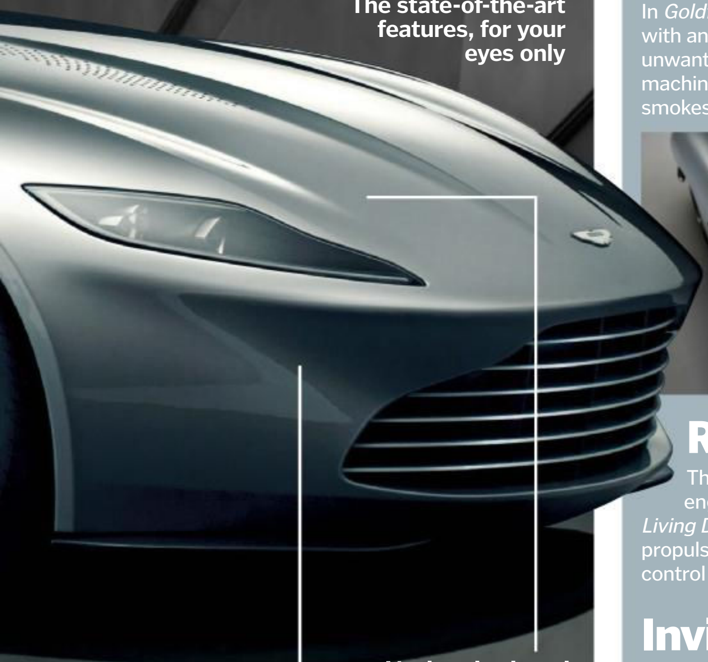
The recent James Bond film *Spectre* sees the world's favourite spy reunited on-screen with his most beloved car brand, the Aston Martin. But of course Bond doesn't drive just any old Aston Martin. The suave secret agent has a long and colourful history of being handed the keys to the most tricked-out, gadget-stuffed ride on the planet – right before he goes and ruins it. But this is all just fantastical fiction, right?

Actually: wrong. A growing number of jittery celebrities – including ex-Spice Girl Mel B and rapper Kanye West – have been investing in armoured vehicles, many of them bristling with features like electric shocking door handles, aimed to deter paparazzi and would-be carjackers. From the outside, these vehicles are indistinguishable from the standard models, but to their occupants they are four-wheeled fortresses that lend them peace of mind as they travel from A to B.

US firm Texas Armoring Corporation (TAC) outfits as many as 100 such "personal protection" vehicles per year. According to CEO Trent Kimball, though, paranoid actors, musicians and sports stars make up only a small minority of the company's clientele. Instead, most of their vehicle upgrades are performed for what Kimball terms "high net worth individuals" travelling in places where there is a very real, very serious kidnap-for-ransom risk.

Aston Martin DB10

The state-of-the-art features, for your eyes only



Up to speed

In the *Spectre* trailer, Q reveals that the DB10 can go from 0-97km/h (0-60mph) in 3.2 seconds.

Under the hood

The car's inner workings are based on those of the V8 Vantage, including its 4.7-litre (1.2-gallon) V8 engine.

THE BEST BOND CAR GADGETS

Ejector seat

In *Goldfinger*, Bond's Aston Martin DB5 is equipped with an ejector seat for swiftly removing any unwanted passengers. The car also has built-in machine guns, tyre spikes and can create a smokescreen to help fend off the enemy.

Submarine car

007 can navigate land and sea with his Lotus Esprit S1 in *The Spy Who Loved Me*. It swiftly transforms into a submarine when Bond drives it off the end of the pier, then becomes a car again when he reaches the beach.

Rocket boosters

The Aston Martin V8 Vantage Volante's normal engine isn't powerful enough for 007 in *The Living Daylights*, so his is kitted out with a rocket propulsion system. The armrest also has a built in control panel for operating lasers and missiles.

Remote control

Bond can control his BMW 750iL with his Ericsson mobile phone in *Tomorrow Never Dies*, so he doesn't even need to be behind the wheel. It also has bulletproof windows and electrified door handles to shock any thieves.

Invisibility cloak

In *Die Another Day*, 007 can evade detection by simply activating the adaptive camouflage of his Aston Martin V12 Vanquish, making it disappear completely. He can then deploy the missiles mounted in the front grille to defeat the bad guys.

Defibrillator

When Bond drinks a Martini spiked with poison in *Casino Royale*, he heads back to his Aston Martin DBS V12 to use its built-in defibrillator machine. A quick shock to the chest helps bring his heart rate back to normal again.

In countries like Nigeria, Cambodia, Venezuela, Honduras, Mexico, Saudi Arabia and Oman, kidnap-for-ransom is an everyday occurrence, explains Kimball. For wealthy business people, entrepreneurs and mid-level executives, investing around $80,000 (approx £53,000) to armour a vehicle that will keep themselves and their families safe not only spares them the emotional turmoil that such an attack would involve – it makes financial sense too.

For these clients, keeping a low profile is paramount; they're keen not to draw attention to themselves with bulky, flashy autos that advertise their status. That's why TAC armours its cars from the inside out, leaving the classic shell of the vehicle in tact, with little hint of its inner strength. "These tend to be luxury vehicles," explains Kimball, "and we want to make sure we put them back as close to the original as possible."

The entire frame of the car is reinforced with cutting-edge materials, including high-hardened ballistic steel, Kevlar, aramid fibres and polyethylene, while the windows are replaced with bulletproof glass. By the time the TAC team is finished, the vehicle is bombproof.

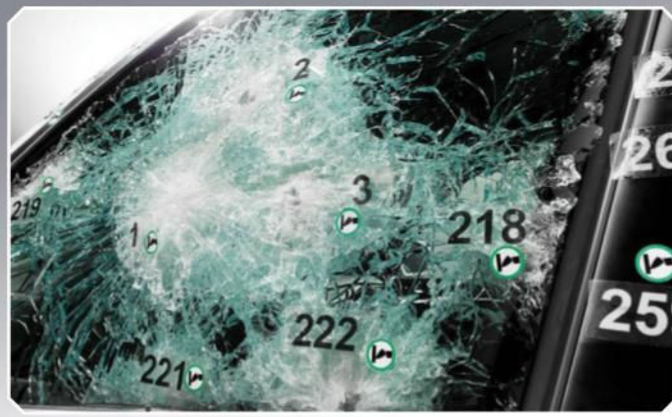
Kimball is so confident in the materials the company uses that he once got behind the wheel of one of their outfitted cars, had an employee aim an AK-47 at his head and instructed them to discharge a round of bullets. Video evidence on YouTube shows Kimball didn't so much as flinch as the bullets cracked lacy patterns into the top surface of the bulletproof glass. James Bond, eat your heart out.

But all that armouring comes at more than just financial cost. There are performance trade-offs as the added weight affects the way the vehicle handles and responds. "Ultimately I need a vehicle that I can turn, that I can stop, that I can do things to manoeuvre out of a kill zone," points out secure transportation expert Joe Autera, who spent over a decade driving high profile clients in some of the most dangerous locations on Earth, and now trains others to do the same.

BMW X5 Security Plus

The first vehicle specifically designed to protect against the world's most widely used firearm, the AK-47

BMW aims to create security vehicles that drive like their normal models



Bullet-resistant glass

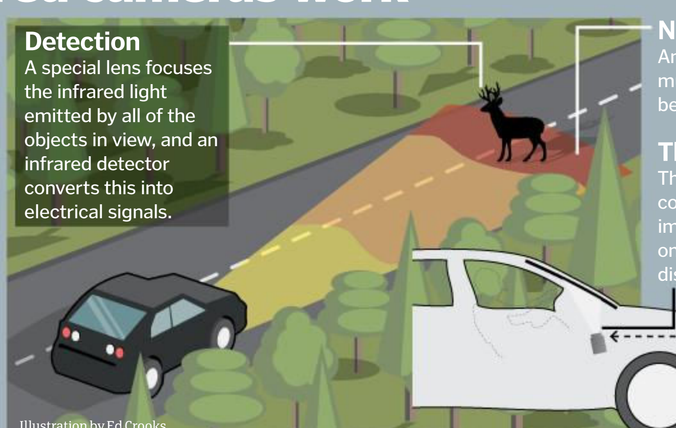
Laminate security glass with a polycarbonate coating protects occupants from bullets and glass shrapnel.

Safety features

The car boasts run-flat tyres, a self-sealing fuel tank, and an attack alarm and intercom system that lets occupants communicate with the outside world without leaving the safety of the vehicle.

How infrared cameras work

Infrared cameras like the BMW Night Vision system allow drivers to perceive their surroundings even in pitch-black darkness. Instead of visible light, which our eyes are built to detect, they 'see' the infrared part of the electromagnetic spectrum. As living things give out heat in this portion of the spectrum, the camera can pick out occupied vehicles and potential human threats.



Detection

A special lens focuses the infrared light emitted by all of the objects in view, and an infrared detector converts this into electrical signals.

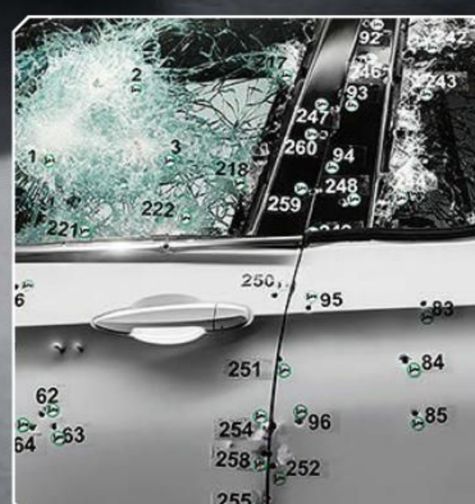
Night vision range

An infrared camera 'sees' much further than high beam headlights.

Thermal image

The electrical signals are converted into a visible image and projected onto the driver's control display unit.

Illustration by Ed Crooks



DID YOU KNOW? *The most popular armoured vehicles on the market today are the Toyota Land Cruiser and the Lexus LX570*

BMW xDrive
An all-wheel drive system adapts to all surfaces and conditions, redistributing power between the front and rear axles accordingly for maximum traction and control.

Interior
Inside, the car is fully equipped with BMW's renowned luxury features and finishing.

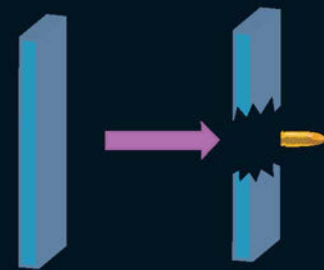
Ballistic protection level VR6
This provides effective defence against terrorist attacks, shrapnel, and automatic weapons like the AK-47.

Armour
Passenger cell protected by a steel armour sheath; aramid and polyethylene sealed joints provide protection where body panels meet.

How bulletproof glass works

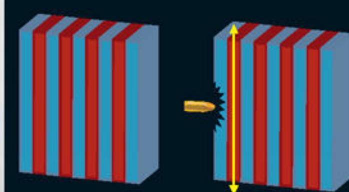
Ordinary glass

Glass is brittle, meaning that it fractures easily when subjected to stress. When a bullet strikes it, glass can't bend to absorb the energy gradually (in the way you might track your hand back when catching a fast-moving ball). Instead, it shatters, allowing the bullet to pass straight through with almost no loss of momentum.



Bulletproof glass

Technically 'bullet-resistant', since no glass is 100 per cent bulletproof, this material is made by sandwiching layers of an elastic polycarbonate plastic (red) between sheets of toughened glass (blue). When a bullet hits, the outer glass layers still break but the plastic stops them from flying apart. The bullet's energy is dissipated sideways through the multiple layers, which quickly brings it to a stop.



How run-flat tyres work

1 Everyday use

Under normal conditions, both conventional and run-flat tyres maintain constant air pressure, providing a flexible cushion that absorbs shock and increases traction between the vehicle and road.

2 Puncture

After a puncture, conventional tyres drop in pressure immediately. Run-flat tyres have a reinforced sidewall that helps the tyre maintain its shape and stops the wheel rim making contact with the road.

3 Post-puncture

Even when completely depressurised, run-flat tyres can hold out for around 80 kilometres (50 miles), preventing drivers from losing control of their vehicle and allowing them and their cargo to escape danger.

Official state cars

The high-security vehicles that protect world leaders and royalty

The PM's jacked-up Jag

UK Prime Minister David Cameron is chauffeured to and from engagements in a modified Jaguar XJ Sentinel, driven by a Specialist Protection officer from the Metropolitan Police Service. Bombproof doors, steel and Kevlar armouring, bulletproof glass and a grenade-proof floor keep him safe; the elegant leather and wood veneer interior keeps him feeling suave.

The prime ministerial car is escorted by a fleet of unmarked Range Rovers

Her Majesty's motorcar

On state occasions, HRH Queen Elizabeth II travels in one of her two bespoke Bentley State Limousines. Gifted to her in 2002 to commemorate her Golden Jubilee, these heavily armoured carriages feature rear-hinged doors for elegant entry and exit, and removable panelling to customise the visibility of their occupants.

The Queen and her head chauffeur had an input on the design of the Bentleys

Meet Obama's motorcade

Why are so many vehicles necessary and what do they all do?

Route car
A local police car sweeps about five minutes ahead of the motorcade, ensuring the route is clear.

Pilot car
Another car runs a minute ahead of the motorcade, validating that the route is clear.

Lead car
A marked police car guides the motorcade.

Spare
This is a decoy vehicle identical to the one the president rides in.

Stagecoach
The president officially rides in this vehicle, although in reality he could be hidden anywhere in the motorcade.

Halfback
This SUV carries the president's Secret Service protection detail.

Codename classified 1
An electronic countermeasures vehicle detects improvised explosive devices or incoming missiles, and sends out jamming signals.

Protecting the President

With four American presidents assassinated, and others having suffered attempts on their lives, Barack Obama needs to know his ride is safe. Cadillac One, otherwise known as The Beast, has armour at least 12.7 centimetres (five inches) thick, and its reinforced doors weigh as much as those of a Boeing 757.

While the majority of The Beast's security features are classified, we do know that the seven-seater has its own oxygen supply, carries a bank of the president's blood, and is fitted with smoke and teargas cannons. Cadillac One, along with a portion of the presidential motorcade, accompanies President Obama all over the world in a trio of military transport planes.

Cadillac One is piloted by a specially-trained Secret Service driver

Autera pegs TAC's vehicles as some of the best in the business because they use the lightest weight ballistic steel on the market and strive to find a good balance between extreme armouring and preserving high-end vehicles' original capabilities.

"The armour is only going to be used once in the vehicle's lifetime," explains Kimball, "but the vehicle is used daily, so you want it to perform like a regular vehicle." To ensure that's the case, TAC replaces components of the braking and suspension systems with meatier versions, and reprogrammes the vehicle's computer to eke out the best performance under the new weight conditions.

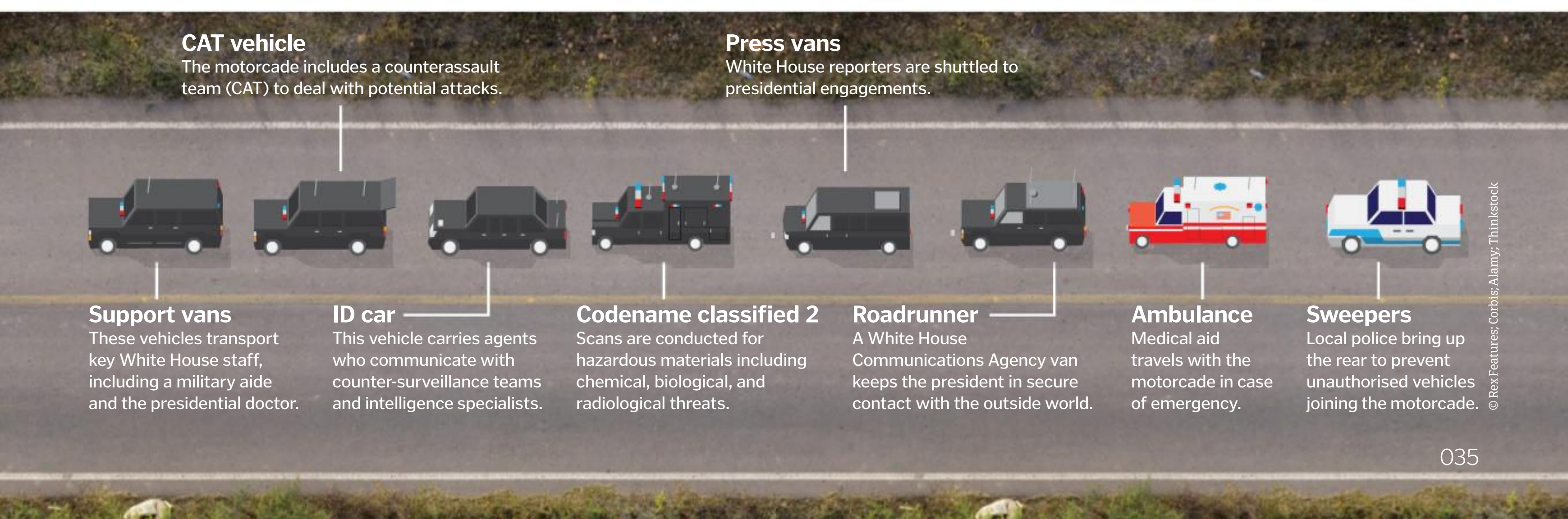
Nevertheless, armoured vehicles handle differently to their conventional counterparts, making specialised driver training essential. Autera schools private sector, government, military and law enforcement personnel in evasive driving, vehicle counter-ambush and counter-carjacking techniques, and offensive driving. "An essential part of protecting someone in a high-risk environment is an armoured vehicle," he says.

And Autera should know. "We were attacked by a group that was trying to stop our motorcade and either kidnap or assassinate the principal," he recalls of one incident during his time as a driver. "They tried to block our path and they engaged the vehicles with AK-47s. We were able to evade the blocking vehicle and, because we were in armoured vehicles, even though our vehicles took fire, none of the rounds penetrated."

Confidence and composure are critical in such high-stake situations. "You can't inoculate somebody against the response to stress," Autera explains. But training helps drivers to recognise the effects of extreme adrenaline – the narrowing field of vision, muffled hearing, and loss of motor skills – and overcome these to take the necessary actions to move their vehicle and passengers out of danger. "That confidence is essential to survival," he says, "because an armoured vehicle simply buys you time."

Electronic countermeasures

These devices protect a convoy from deadly phone call threats



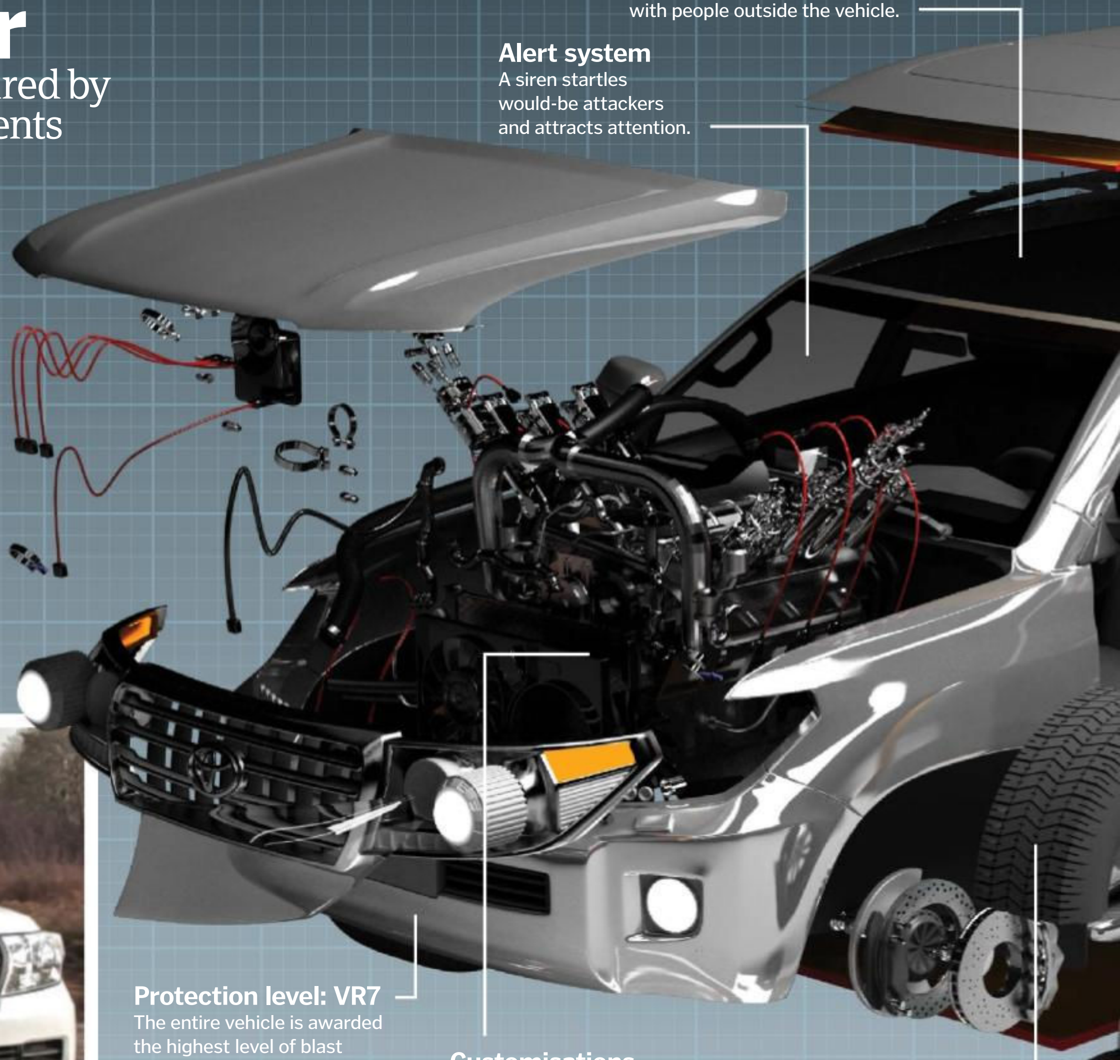
Inside the Jankel Land Cruiser

The armoured SUV 200 favoured by military, NGOs and governments

Industry leader Jankel produces armoured vehicles for police, international security forces and military clients worldwide. Their armoured Toyota Land Cruiser 200 offers extreme blast protection that makes it popular with humanitarian and security organisations operating in hostile environments like warzones.

Its armour is hot-formed, meaning it is heat-moulded to the vehicle from just 31 individual pressed panels (as opposed to the hundreds of pieces used in conventional armouring approaches). This kind of armouring is quicker to complete and the finished product is cheaper, lighter, and more protective than any other alternative.

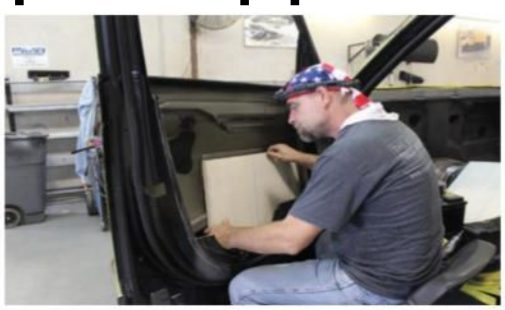
The entire vehicle goes through extensive live-fire and blast testing, including ballistic rounds fired, hand grenades detonated on its roof, mines detonated under the seats, and 15 kilograms (33 pounds) of TNT detonated two metres (6.6 feet) from the side door. Its performance in these tests earns it a protection certification at one of the highest levels available: VR7.



Hot-formed armour reduces welding and bolting by 70 per cent

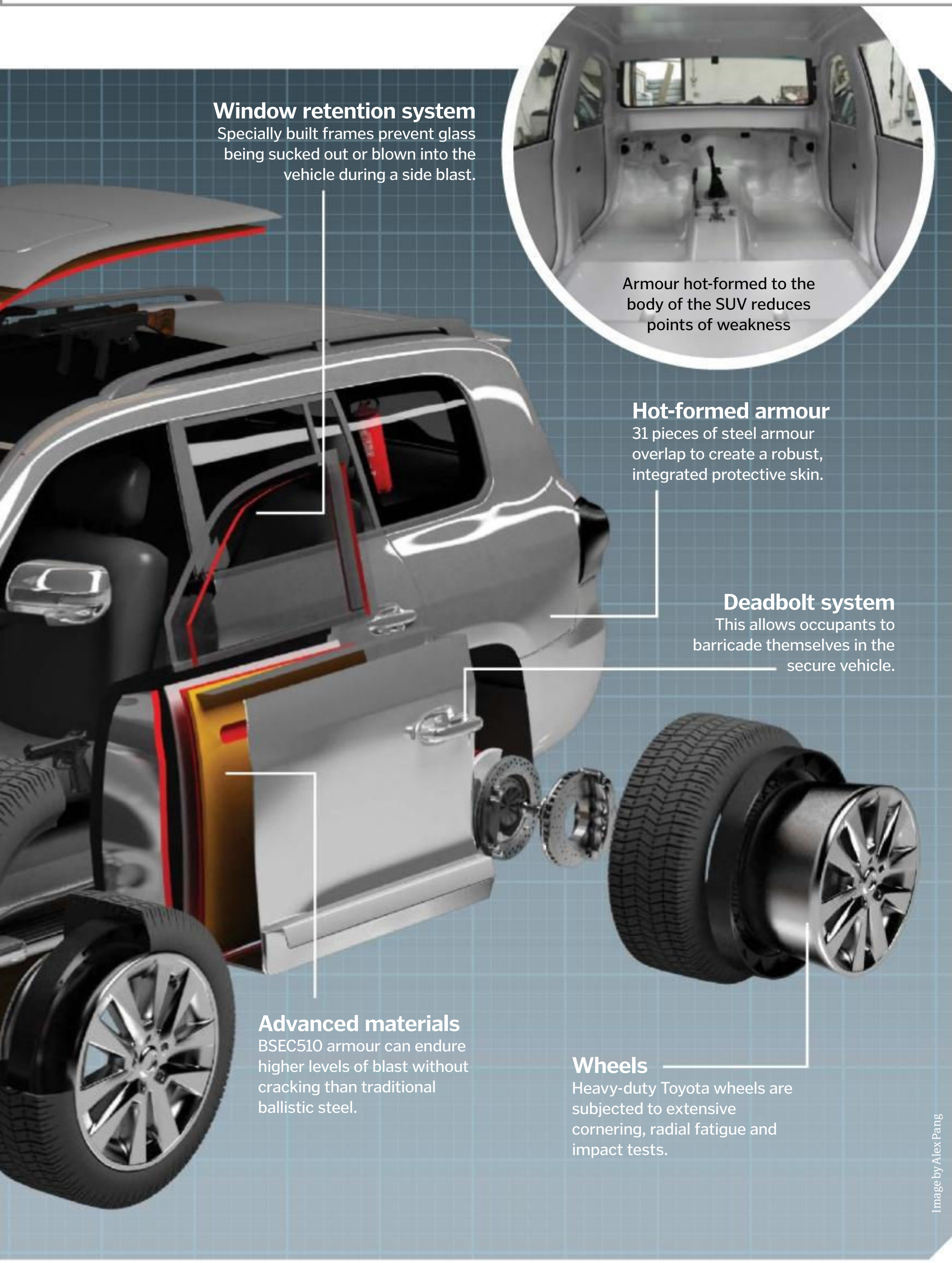
How Texas Armouring Corporation equips their vehicles

1 Gutting
The vehicle is completely stripped. Everything on the inside – seats, floor, roof, carpet, headliners and dashboard – is ripped out, until the vehicle becomes no more than a frame. It is then ready to be lined with armoured materials.



2 Opaque armouring
The body of the vehicle – including doors, floor, roof, fire wall and pillar posts – is lined with advanced protective materials including lightweight composite armour, high-hardened ballistic steel, Kevlar and aramid fibres, and ballistic nylon.

3 Transparent armouring
The windshield, back glass, and door glass are all replaced with five-centimetre (two-inch) thick bulletproof glass. As it is so deep, everything surrounding these windows must be modified to allow the glass to fit.



This is where those electric shocking door handles come in. "We just want them to be able to get out of a situation, to give them any time they need," stresses Kimball. Unlike the armouring, he sees this sort of addition as an accessory. "That type of thing is fun to talk about, but it's not the life-saving technology," he explains, adding that often clients request things they've seen in Hollywood movies.

Other features that might just buy would-be victims a few extra moments to escape danger include a blinding smokescreen that can be belched out of the back of the car if someone fears they're being followed, and a road tack dispenser that drops spikes onto the road to lacerate the tyres of pursuing vehicles.

Of course, there are more serious additions too. Run-flat tyres – which use either reinforced tyre walls or hardened plastic inserts – can hold out for about 80 kilometres (50 miles) after tyres have been shot, and give a driver the chance to put some solid distance between themselves and their adversaries. A secure deadbolt locking system overrides the automatic lock release that usually happens when a car gets hit – a feature that professional kidnappers have previously been known to exploit.

Finally, internal parts like the fuel tank are also armoured – but not for the reason you might think. "A lot of times in the movies, they shoot at your fuel tank and it automatically explodes. That just doesn't happen," laughs Kimball. Fuel won't catch fire in the absence of a spark, but enough well placed shots could cause a problematic leak and affect getaway capabilities. Self-sealing foam ensures that this doesn't happen.

"Life is valuable. Protect it," runs the TAC slogan. While they may not yet be able to boast invisibility-cloaking devices – like Mr Bond's in *Die Another Day* – these fully loaded security vehicles give ordinary people priceless peace of mind in areas where the threat of armed violence is ever present.

4 Suspension and braking upgrade
Since added armour can weigh anything from 500 to 750 kilograms (1,100 to 1,650 pounds), the vehicle must be fitted with stiffer suspension springs and more heavy-duty shocks. Brake rotors and pads are replaced with racing car parts, to allow faster stopping.

5 Parts and accessories
The fuel tank, radiator, and computer modules are fitted with armour, run-flat tyres are installed and if the client requested operable windows, the motors for these are installed, as well as any extras like a smokescreen system, road tack dispensers, or shocking door handles.

6 Interior re-install
Workers in the 'trim shop' reshape the original interior to fit the new dimensions and contours of the armoured vehicle, endeavouring to match it as closely as possible to the original, unless the client has requested custom colours, fabrics or seating configurations.

The Pit-Bull VX

Fast, agile and bulletproof, this armoured response vehicle is one of a new breed of robust police cars that are stopping criminals in their tracks

The Pit-Bull VX is an armoured response vehicle (ARV). Designed specifically for SWAT teams, ARVs offer protection against small arms fire, but without the heavy armour that military vehicles require for protection against cannon fire and anti-tank weapons.

Lighter armour than their military equivalent gives ARVs greater speed and agility. This makes them suitable as first-response vehicles in an emergency situation. Once at a hostile scene an ARV's tough shell means it can be used tactically as a firing post, for dropping an assault team into position or for rescuing hostages.

In the past police teams have tended to use either commercial pick-up trucks or vans. These provide a reasonably fast response time, however offer little more than the means of getting them to a hostile scene. Some SWAT teams have started to drive military vehicles, but due to their weight and lack of mobility they are not designed to be the first responders to an emergency.

ARVs like the Pit-Bull offer a compromise between the speed of an unarmoured vehicle and the protection of an armoured one. As well as offering its eight-officer crew protection against small arms fire, the Pit-Bull is grenade-proof, while firing ports enable the police to use their weapons from within. A PA system and remote-control floodlights mean they can also communicate with the assailants and illuminate an area without having to step out of the vehicle. To cap it all, if negotiations do break down, the 7.5-ton Pit-Bull VX's front bumper has been specially designed to be used as a battering ram.

Inside the mobile fort

Every effort has been taken to make the Pit-Bull VX invincible. Learn how here…


The Pit-Bull VX is designed to cope with high-powered rifles, grenades and even mines

Making an armoured Pit-Bull

The Pit-Bull VX starts life as a Ford F-550. A heavy-duty, four-wheel-drive pick-up truck, it's a workhorse of the US construction industry. The 6.7-litre V6 engine and transmission of the F-550 and chassis remain in the Pit-Bull VX. However, everything else is armoured or purpose built.

The fuel tank, battery and exhaust pipe are fitted with steel armour plating and the suspension is also strengthened. Tubeless run-flat tyres are installed, which function at speeds of up to 48 kilometres (30 miles) per hour when punctured.

In the event of the tyres being shredded the Pit-Bull VX can still operate on its military-grade wheel rims. Ballistic steel plate is used to provide a mine and grenade-resistant floor, while the main body is made up of overlapping armour plating.

This is built and tested to US National Institute of Justice (NIJ) standards. Despite the armour, the overall weight of the Pit-Bull is 1,000 kilograms (2,200 pounds) less than the F-550 maximum operating limit – plus it still manages to maintain the same speed and performance.

Bulletproof glass

A bulletproof windscreen and windows mean the Pit-Bull VX crew have excellent visibility yet are still protected if they come under fire. Modern bulletproof, or ballistic, glass is constructed in the same way as laminated windscreens. Thin layers of polycarbonate – a transparent plastic – are glued between sheets of glass. The outer layer of glass is often softer so it will flex with the impact of a shot rather than shatter.

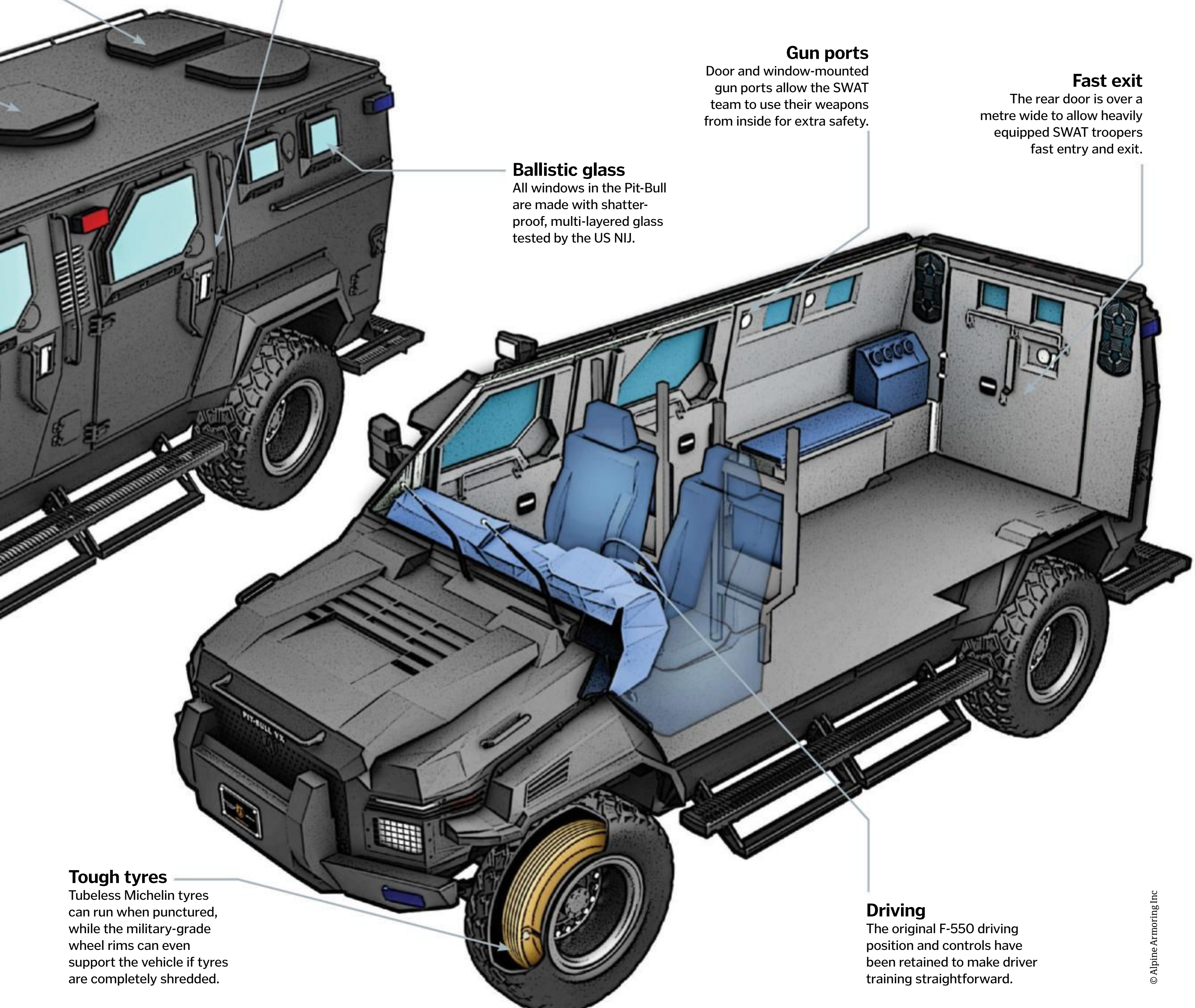
A bullet would pierce the outer sheet of glass, but the polycarbonate absorbs the bullet's energy, stopping it from penetrating the inner layer of glass. Depending on the protection levels offered, a bulletproof pane of glass may be comprised of numerous layers of glass and polycarbonate. The Pit-Bull's windows offer protection right up to 7.62 x 51-millimetre (0.3 x 2.0-inch)-calibre ammunition – eg an AK-47.

No gaps
Armour overlaps on all five doors so there's no entry point for bullets.

Gun ports
Door and window-mounted gun ports allow the SWAT team to use their weapons from inside for extra safety.

Fast exit
The rear door is over a metre wide to allow heavily equipped SWAT troopers fast entry and exit.

Ballistic glass
All windows in the Pit-Bull are made with shatter-proof, multi-layered glass tested by the US NIJ.



Tough tyres
Tubeless Michelin tyres can run when punctured, while the military-grade wheel rims can even support the vehicle if tyres are completely shredded.

Driving
The original F-550 driving position and controls have been retained to make driver training straightforward.

Eco cars evolved

See how modern electric cars are stepping up a gear…

Battery electric vehicles (BEVs) have been around for longer than you would expect. The first examples of cars powered by electricity were in the early-19th century, and were commonplace until the internal combustion engine took over. The first examples were very basic and couldn't be recharged. However, the modern-day BEV has evolved a lot since back then and has overcome technical difficulties that made them previously unsuitable for our roads.

Charging time has always been a big issue among the motoring community where BEVs are concerned. Previous examples of BEVs have usually had charging times of around 8-12 hours from UK sockets. This time has been dramatically reduced by new technologies explored by manufacturers like Nissan with the Leaf. Indeed, the Leaf can be charged from flat to 80 per cent capacity in around 30 minutes from a special charging port.

Nissan has also applied some very creative theories to improve the overall efficiency of the Leaf. For example, the front LED lights are designed to deflect airflow away from the wing mirrors. This reduces aerodynamic drag acting on the car, so that less power is needed to propel the vehicle forwards.

Whereas existing BEVs have had issues with large battery packs taking up cabin space, the Nissan engineers have developed theirs to free up space. This is achieved by having the thin 24-kilowatt-hour battery pack underneath the floor. This also has the added benefits of improving handling and structural rigidity.

Modern BEVs are becoming increasingly technologically advanced, with the Leaf having a dedicated app for smartphones. This can be used to start a charging session, activate climate control and to check estimated driving range information without leaving your sofa.

Inside the new Nissan Leaf

Take a look at the cutting-edge technology powering the Nissan Leaf electric car

Eco car timeline

We track the rise of electric-powered vehicles from their conception to today

1830s
First electric carriage
Scotsman Robert Anderson builds and drives a basic (non-rechargeable) electric carriage.

1897
Electric cabs
The Pope Manufacturing Company becomes the first large-scale electric car maker, filling the NYC streets with electric taxis.

1899
Speed record
The French-built 'La Jamais Contente' becomes the first electric car to reach 100km/h (62mph).

1920s
Internal combustion engine
By the end of the Twenties, the electric car is surpassed by combustion engines.

Power plant
The 'engine' is a 80kW (110hp), 280Nm (210ft lb) electric motor with a top speed of 150km/h (93mph).

Charging up with Quimera RR

Quimera Responsible Racing is a company that produces spectacular all-electric race cars. Its AEGT, which stands for All Electric Gran Turismo, is considered a masterpiece of space-age technology.

It has not one but three electric motors, which propel the AEGT from 0-60mph in three seconds. The battery pack and motors produce 522 kilowatts (700 horsepower) of power, and 1,000 Newton-metres (738 foot pounds) of torque, which can be applied instantly. These battery packs are positioned as low as possible to ensure that the handling of the car is kept sharp and manoeuvring is nippy.

In many ways the AEGT is a rolling laboratory, where the innovations and developments can be tested for implementing into road-going electric cars for the future.

Advanced aerodynamics
The front LED lights are designed to deflect air away from the wing mirrors. This reduces aerodynamic drag, increasing efficiency.

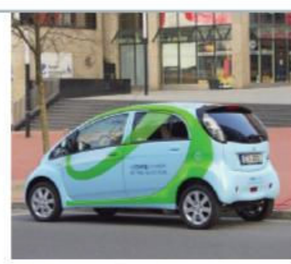
Charging port
The car can be charged from 0-80 per cent capacity from the front of the vehicle in 30 minutes.

Drivetrain
Due to instant torque from the motor, there is no need for gears and clutches.

1966
GM Electrovan
This has been credited as being the first-ever hydrogen fuel cell car produced.

2004
Electric sports car
Tesla Motors begins development of the Roadster, which has been sold in over 31 countries to date.

2010
Mass production
The Mitsubishi i-MiEV becomes the first EV to sell more than 10,000 units.



2014+
The future
Eco cars are primed to compete with combustion engine cars, with extended ranges and faster charging times.

© Nissan

Superbikes

So fast that some have been sanctioned as illegal, the current generation of superbikes are changing the nature of two-wheeled transport. We take a look at some of the most notable and the advanced technologies they employ

Optimised for extreme acceleration, braking and cornering, superbikes are aggressive, mass-centred machines designed with one thing in mind – pure speed. And it is a mission that nothing can stand in the way of; there is no compromise. Comfort? Forgotten. Fuel economy? Laughable. Legality? Somewhat questionable.

Superbikes are completely transforming the levels of speed at which a human being is capable of travelling on two wheels, pushing the boundaries of performance that few hypercars can better and for a fraction of the cost. Driven by the blurring of the lines between professional MotoGP superbikes and those available to the public – as well as the collapse of a gentleman's agreement between bike manufacturers to limit their vehicles to maximum top speeds of 200mph – superbikes are breaking loose from traditional constraints with the help of next-generation technology.

Superbike basics work by adopting the traditional design elements of motorcycles and refining and evolving them to maximise speed and performance. First, engine power is increased – often well over one litre (1,000cc) – and encased within an aluminium alloy frame to reduce weight. The engine is also rebuilt from scratch from lightweight composite materials (see 'Inside a superbike engine' boxout) and repositioned to maximise weight distribution, structural integrity and crucially, chassis rigidity. The latter is important as it affects dynamism and stability when accelerating, braking and cornering. The motorcycle's geometry is also completely rewritten in order to ensure correct front-to-rear weight distribution and rider positioning for high speed riding.

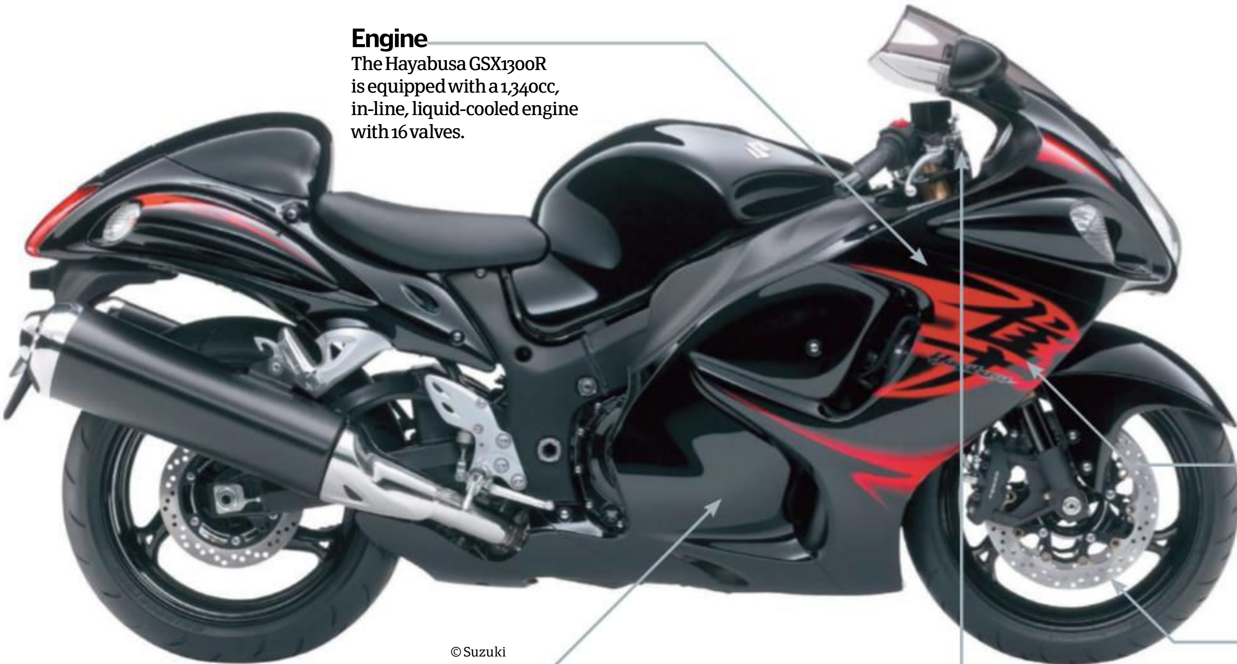
These design alterations include a smoothing of the bike's chassis to increase aerodynamic performance and to reduce the amount of drag, as well as the repositioning of instrumentation and

Hayabusa GSX1300R

The statistics…

Hayabusa GSX1300R

Length: 2,190mm
Width: 724mm
Height: 1,166mm
Wheelbase: 1,481mm
Mass: 260kg
Engine: Four-stroke, liquid-cooled, DOHC
Power: 145 kW @ 9,500rpm
Torque: 155N.m @ 7,200rpm
Clutch: Wet multi-plate
Transmission: Six-speed constant mesh
Gearshift: One-down, five-up



Engine
The Hayabusa GSX1300R is equipped with a 1,340cc, in-line, liquid-cooled engine with 16 valves.

Transmission
The GSX1300R is kitted out with an optimised six-speed transmission. Oil is automatically sprayed to the 4th, 5th and 6th gears to reduce wear and mechanical noise.

Brakes
Radial-mount front brake callipers allow the GSX1300R to be fitted with smaller 310mm front brake rotors to reduce unsprung weight and improve handling. A single piston rear brake calliper works in conjunction with a 260mm rear brake disc.

Chassis
Made entirely from aluminium, the frame is designed to maximise strength while minimising weight. This is evident in the bike's bridged aluminium swingarm.

Instrumentation
The instrumentation features four analogue meters for the bike's speedometer, tachometer, fuel gauge and water temperature.

The Hayabusa GSX1300R features an optimied six-speed transmission

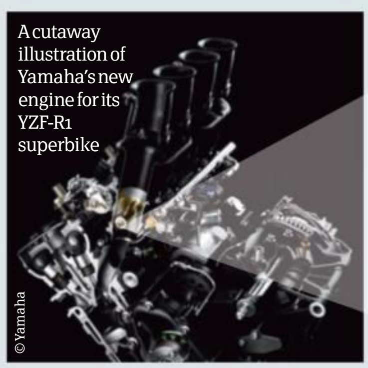
controls – such as higher foot pegs and lower handlebars – to ensure optimised rider positioning.

Superbikes also feature a plethora of advanced and upgraded components and technologies. In terms of braking, thicker high-grade brake pads are used in conjunction with larger iron, carbon or ceramic-matrix disc brakes, which in turn are fitted with multi-piston callipers clamped onto oversized vented rotors. Suspension systems are multi-adjustable at both the front and rear – which allows adjustment for road conditions and riding style – and wheel forks are fitted with independent left and right cushioning to improve damping performance (the reduction of friction and oscillation at high velocity). Engine crankshafts (the part of the engine that translates the reciprocating linear piston motion of the power stroke into rotational motion) are also custom built to ensure a smoother combustion process. On top of this, each superbike's transmission is modified to use with

Inside a superbike engine

Why do they have such explosive performance?

Almost all modern superbikes have extensive liquid-cooling systems and smart composite materials to improve cooling and heat transfer while in operation. Further, many components are made from lightweight aluminium alloys and are covered with chrome-nitride coatings to reduce friction. Combustion efficiency is achieved by employing iridium spark plugs in conjunction with refined fuel injection systems. In addition, advanced engine firing systems are used to improve the smoothness of energy transfer to the road, as demonstrated in the crossplane crankshaft installed on the Yamaha YZF-R1. Here the YZF-R1's crankshaft is designed to fire unevenly in order to produce combustion rather then inertial torque. This improves power, smoothness and rider feel when riding at speed.



A cutaway illustration of Yamaha's new engine for its YZF-R1 superbike

The crossplane crankshaft from the YZF-R1

dual wet, multiplate clutches (see 'Superbike transmission explained' boxout) for lightning-fast and super-smooth gear changes. Both front and rear tyre sizes are also dramatically increased in order to increase traction and maximum riding angle.

Finally, superbikes are kitted-out with numerous smart electronic systems in order to help the rider control the extreme power and speed at which they are travelling. These range from traditional tachometers, speedometers and rev-counters through to automatic systems to control intake performance across the bike's rpm range and throttle-valve opening timings for responsive and smooth power.

Kawasaki Ninja ZX-10R

Instrumentation
The ZX-10R features a LED-backlit bar-graph tachometer which allows different modes to be selected to suit use.

Traction control
The Sport-Kawasaki Traction Control technology is installed to maximise forward motion.

© Kawasaki Motors Europe

Engine
The ZX-10R's engine delivers a maximum power output of 147.1 kW at 13,000rpm. The engine has been tuned by Kawasaki to help ensure a smooth ride.

Chassis / exhaust
Fitted with next-generation exhaust header pipes formed from heat-resistant titanium alloy and sporting a new curved chassis to increase aerodynamic performance.

Suspension
The ZX-10R sports horizontal back-link rear suspension above the bike's swingarm. This arrangement increases road holding in the final third of the engine's stroke range and increased stability when cornering.

The statistics...

Kawasaki Ninja ZX-10R

Length:	2,075mm
Width:	714mm
Height:	1,115mm
Wheelbase:	1,425mm
Mass:	201kg
Engine:	Four-stroke, liquid-cooled, in-line four
Power:	147.1 kW @ 13,000rpm
Torque:	112N.m @ 11,500rpm
Clutch:	Wet multi-plate
Transmission:	Six-speed return
Gearshift:	One-down, five-up

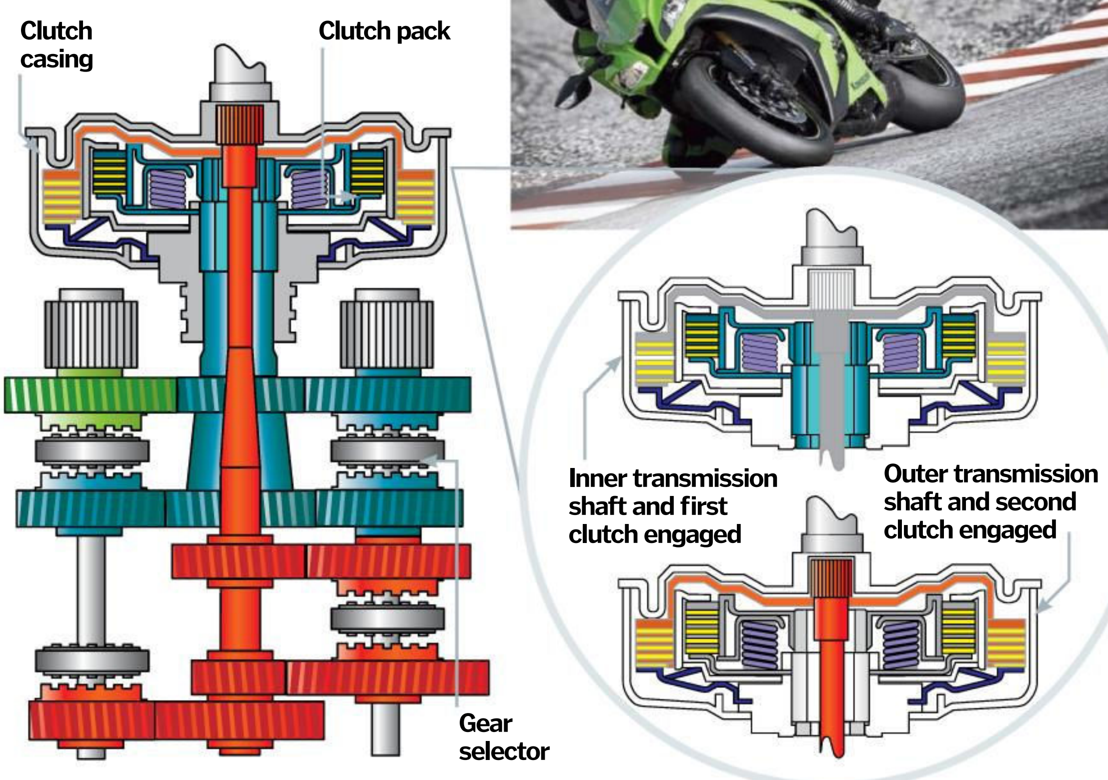
Superbike transmission explained

Because it takes two to transmission

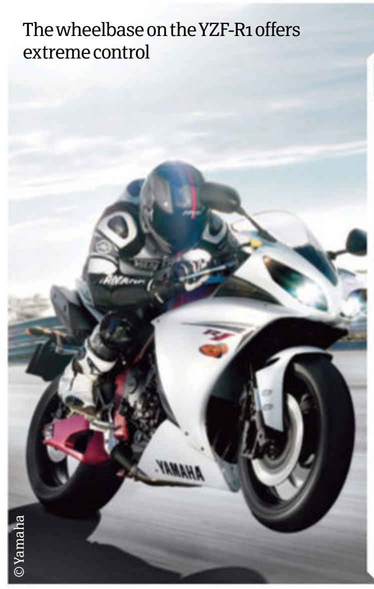
Modern superbikes use dual-clutch transmissions for maximum performance. These work by having two clutches instead of the usual one sharing the gearbox, with each clutch attached to half the amount of total gears. In essence this means that when the bike is in a certain gear the next gear is also selected by the second clutch. Consequently, when the rider changes up a gear and the first clutch is disengaged, the second clutch can instantly engage the next gear, providing a super-fast response time.

Due to the compact, advanced design of the superbike dual-clutch transmission, most systems on the market use wet multi-plate clutches. Wet clutches involve submerging the clutch components in lubricating fluid to reduce friction and limit the production of excess heat. This is due to the fact that wet multi-plate clutches use hydraulic pressure to drive the superbike's gears. This works as when the clutch engages, hydraulic pressure from its internal piston forces its series of stacked plates and toothed friction discs against a fixed pressure plate. In turn, the friction discs mesh with the splines on the inside of the clutch drum and the force is transferred from drum to gearset.


The Kawasaki Ninja ZX-10R boasts sophisticated traction control
© Kawasaki Motors Europe



Yamaha YZF-R1



The wheelbase on the YZF-R1 offers extreme control

© Yamaha

The statistics...

Yamaha YZF-R1

Length: 2,070mm
Width: 714mm
Height: 1,130mm
Wheelbase: 1,415mm
Mass: 205kg
Engine: Four-stroke, liquid-cooled, DOHC, forward inclined
Power: 133.9 kW @ 12,500rpm
Torque: 115.5 Nm @ 10,000rpm
Clutch: Wet, multiple-disc coil spring
Transmission: Six-speed, constant mesh
Gearshift: One-down, five-up

Engine
The YZF-R1's engine is a four-stroke, liquid-cooled variant. It delivers a maximum power output of 133.9 kW at 12,500 rpm.

Electronics
Yamaha's YCC-I (Yamaha Chip-Controlled Intake) adjusts the length of the four intake funnels of the YZF-R1 for accurate and balanced performance across the rpm range.

© Yamaha

Suspension
The YZF-R1 features multi-adjustable front and rear suspension that can be varied depending on riding style and road conditions.

Crankshaft
The YZF-R1 is the first production bike with a crossplane crankshaft. This grants the rider extra control and feel as the crossplane produces combustion rather than inertial torque.

Wheelbase
Imported directly from Yahama's MotoGP bikes, the YZF-R1 sports a short wheelbase and long swingarm frame which helps deliver maximum traction and control.

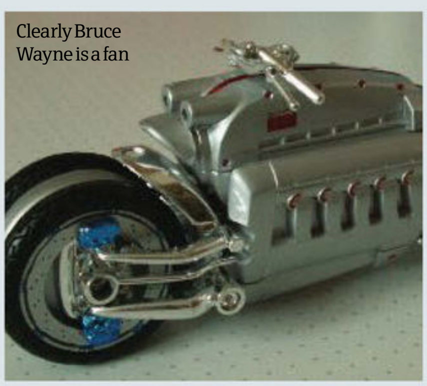
Dodge Tomahawk

When $500 million meets 500bhp

Costing over $500 million and sporting the 500bhp, 8.3-litre V10 that can be found in the Dodge Viper supercar, the Dodge Tomahawk is the world's fastest superbike. Indeed, it is so powerful – think 0-60 in 2.5 seconds and a top speed of over 400mph – that it has been banned for legal use on public roads. Despite this, however, Dodge has sold more than ten Tomahawks for private collectors for use on racetracks and private estates.

The Tomahawk is constructed from a 356-T6 aluminium alloy block with cast-iron liners and a series of aluminium alloy cylinder heads. The bike is cooled by twin aluminium radiators mounted atop its engine intake manifolds as well as a force-fed belt-driven turbine fan. Braking is handled by 20-inch perimeter-mounted drilled and machined stainless rotors, partnered with multiple four piston fixed aluminium callipers.

Clearly Bruce Wayne is a fan



How It Works fantasy race

How long will it take these two-wheelers to get from Alaska to Argentina, assuming they travel at top speed all the way?

Bike images © Khaosaming, Falcon Motorcycles, Suzuki

Inside the ultimate RV

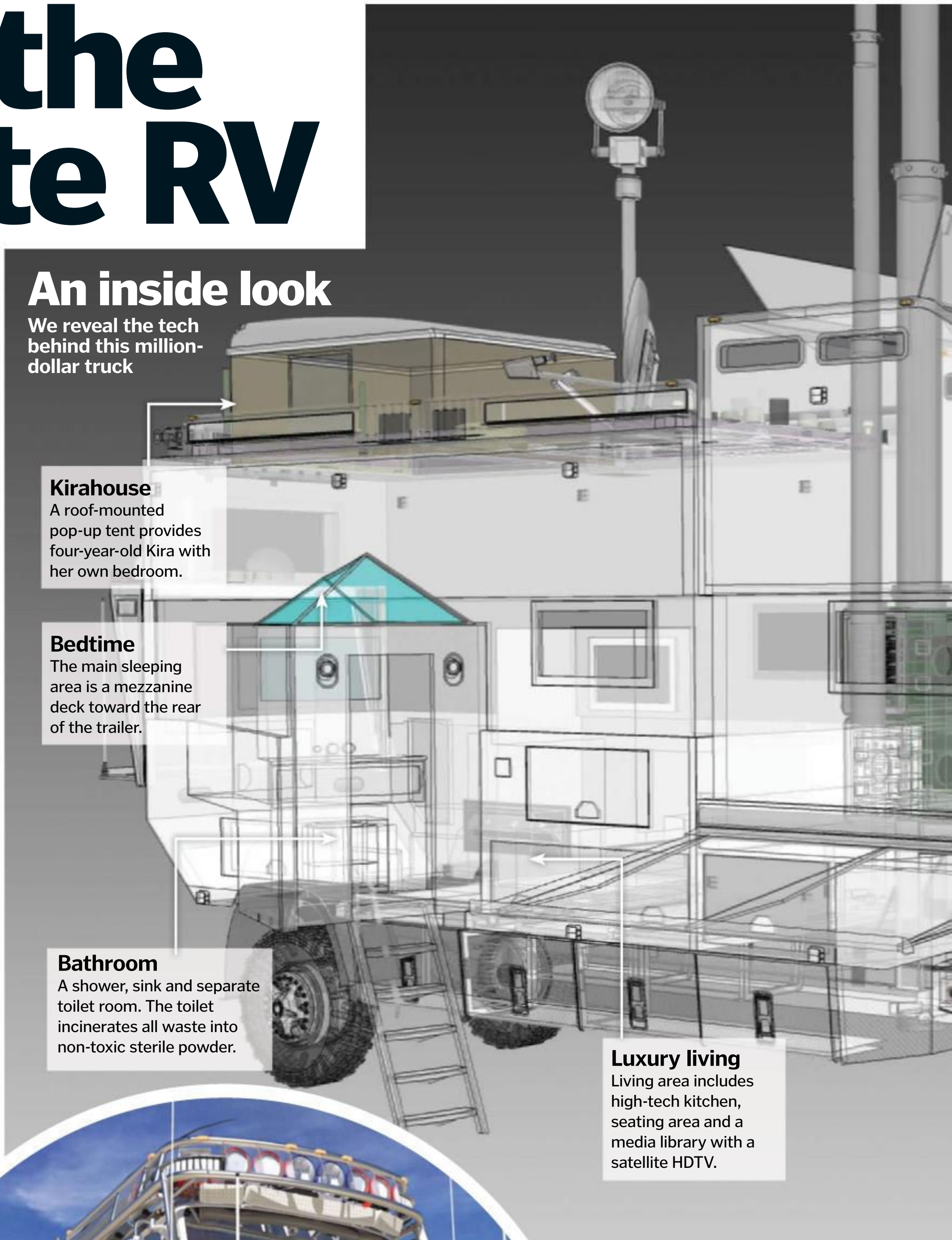
This camper van has everything you need for an adventure

Most fathers want to show their children the world, but American inventor Bran Ferren took that dream a step further. He designed his camper van with an office, kitchen and bedroom, and even a pop-up tent on the roof for his four-year-old daughter Kira, who the KiraVan is named after.

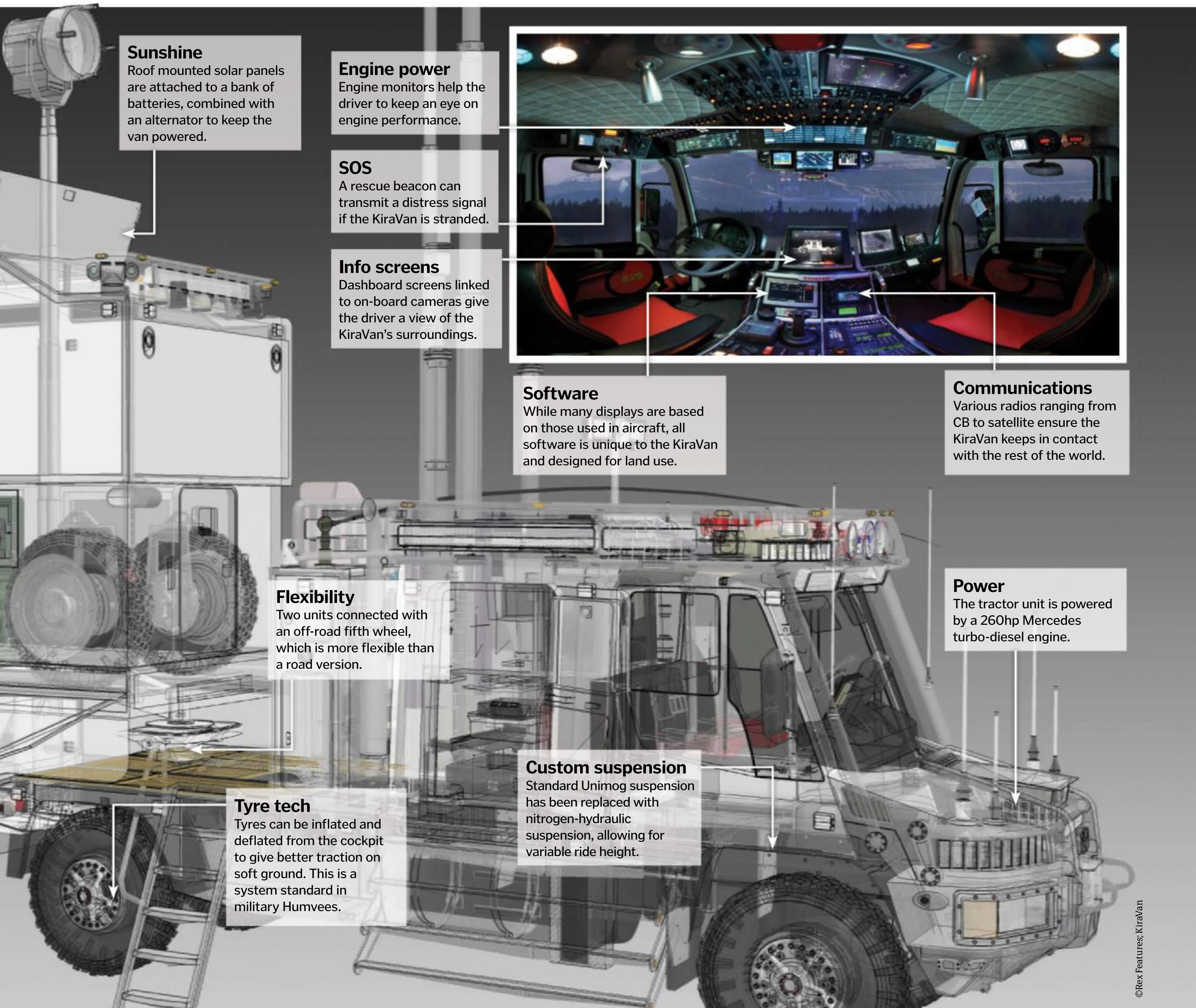
It can travel 3,220 kilometres (2,000 miles) without resupply, powered by a modified Mercedes-Benz Unimog chassis, renowned for their reliability and cross-country performance. The diesel engine has been fitted with sensors to monitor temperature, vibration and torque so the driver has a constant picture of how the engine is performing. A heated fuel tank ensures the diesel won't freeze in low temperatures and also filters the diesel so only clean, pure fuel is fed to the engine for optimum performance.

It's comfortable for the driver too, thanks to the special vibration-reducing chair. The cockpit is surrounded by screens that display road conditions, GPS mapping and weather details. Drones even fly ahead to check on traffic. At 15.8 metres (52 feet) long and over three metres (10 feet) high, the KiraVan uses a tractor-trailer design like an articulated lorry. This gives the trailer off-roading capability by adding a hydrostatic drive system, enabling six-wheel drive at speeds up to 40km/h (25mph). Hydrostatic drives use pressurised fluid in order to drive a motor, negating the need for a drive shaft, which would restrict movement between the two units.

The insulated trailer unit has a bedroom, office, kitchen, living quarters and an eco-friendly bathroom. Slide-out compartments and a motorised rising roof section doubles the internal living space when deployed. You'll find home comforts such as a media library, flat-screen TV and seating area, and enough supplies for to last three people three weeks before having to restock.



DID YOU KNOW? *In the Gulf War, the British SAS used the Unimogs, using them as 'motherships' to resupply Land Rover patrols*



©Rex Features; KiraVan

WORLD'S FASTEST TRAINS

DISCOVER THE LEVITATING TRAINS THAT GO FASTER THAN 300MPH

For many of us, the daily train commute is a slow, boring necessity, but what if you could travel at a mind-bending 430 kilometres (267 miles) per hour? That is the reality for passengers travelling on the world's fastest train, the Shanghai Maglev.

High-speed trains have been around since 1964, when a line between Tokyo and Osaka in Japan was built to reach speeds of 210 kilometres (130 miles) per hour. This shortened the time it took to travel between two of Japan's largest cities dramatically, and the world's love of high-speed rail was born.

Many of the world's fastest trains today use magnetic levitation to achieve daily speeds that are over six times the British motorway limit. However, high-speed travel is possible without using magnets. Britain has plans for its second high-speed rail track, from London to Manchester and Leeds via Birmingham, called HS2. The project's technical director, Professor Andrew McNaughton, explains there are other ways to achieve super-speed. "The point of contact between the steel wheel and the steel track is only the size of your fingernail, so we are not too worried about friction, plus the energy required to levitate a train is huge", he says. "HS2 will have 100 horsepower, which is four times more than [in] normal trains. It will only stop at a few stations so won't have to slow down and speed up often at all."

The proposed HS2 train will drastically reduce the time it takes to get between the south and north parts of England by simply using a more powerful engine and fewer stops. However, even though the engine is more powerful, it doesn't actually use that much more energy. The train will use a big burst of power to get up to speed and essentially coast along after that. It will be able to reach a top speed of 360 kilometres (224 miles) per hour and have an average speed of 230 kilometres (143 miles) per hour on its cross-country journey. This will halve the time it takes to get from London to Manchester.

Whether they are suspended in the air or equipped with a monster of an engine to get them off the starting line, high-speed trains are revolutionising the way we travel.

Jet-powered trains

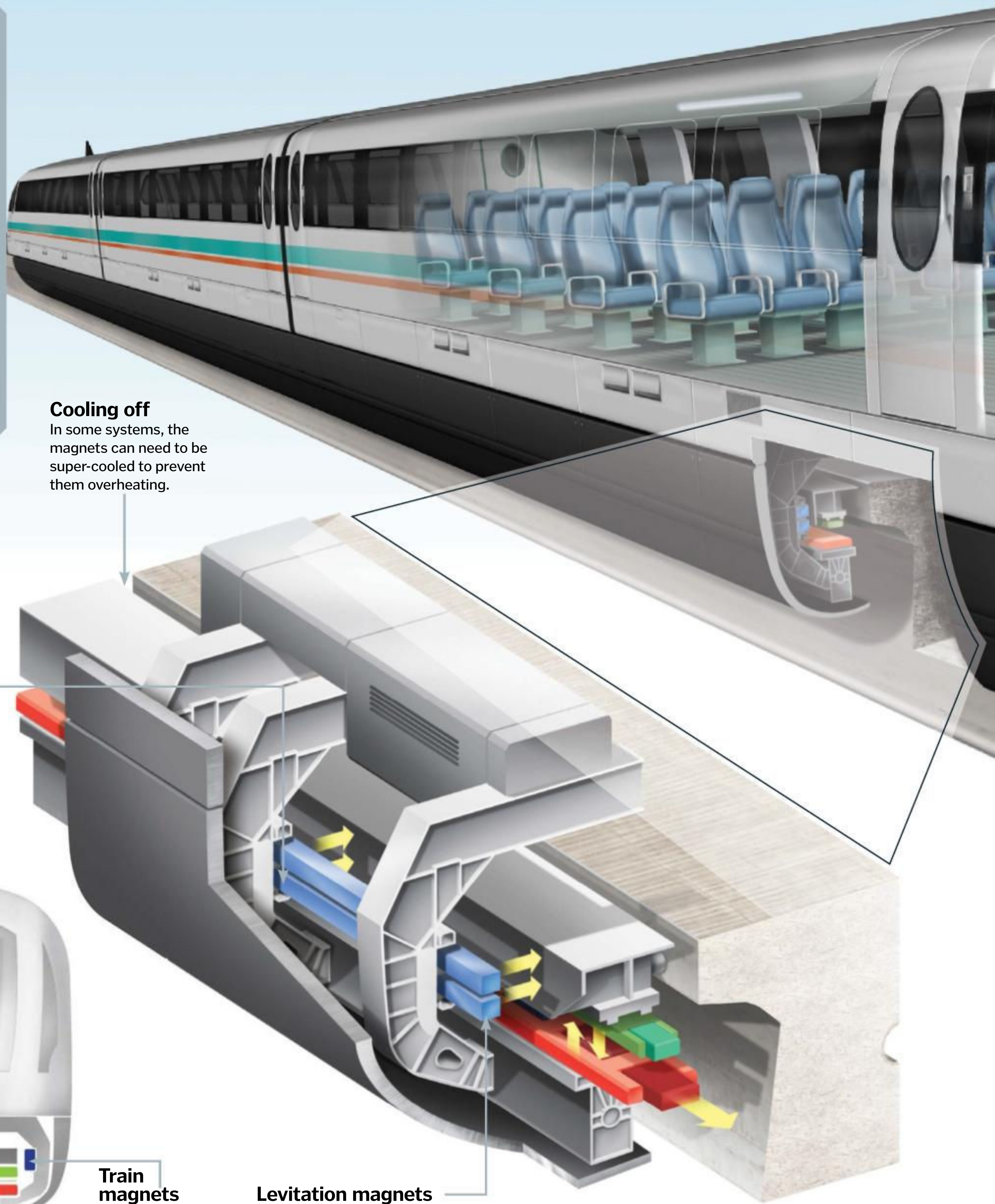
While magnetically driven trains seem to be the future, back in 1966, rockets were all the rage, so naturally someone decided to pop a couple onto a train to see how fast they could go. That person was New York Central Railroad engineer Don Wetzel. He was engaged in an experiment to see how fast he could make a train travel, so used two General Electric J47-19 jet engines on a Budd Rail Diesel Car train with a modified nose for extra streamlining. They named it the Black Beetle and on one run it hit a monumental 295.6 kilometres (183.7 miles) per hour. This remains the record for the fastest train ever to run in the USA, but Wetzel's idea wasn't to last. Rocket-powered trains did not become a viable alternative to steam or electric as they were expensive, difficult to source and provided unmanageable amounts of thrust for commercial use.

Inside a speed machine

How do maglev trains travel hundreds of miles per hour?

Advantages

The obvious advantage is getting to places much, much quicker. The HS2 high-speed train will halve the journey time between the London and Manchester, which will be a great boost to both cities. The Beijing to Shanghai high-speed railway cuts the journey time from nearly ten hours to five. The other huge benefit is that maglev trains don't have engines so there are fewer things that can malfunction. They are solely powered through electromagnets in the track and train and batteries inside the train.



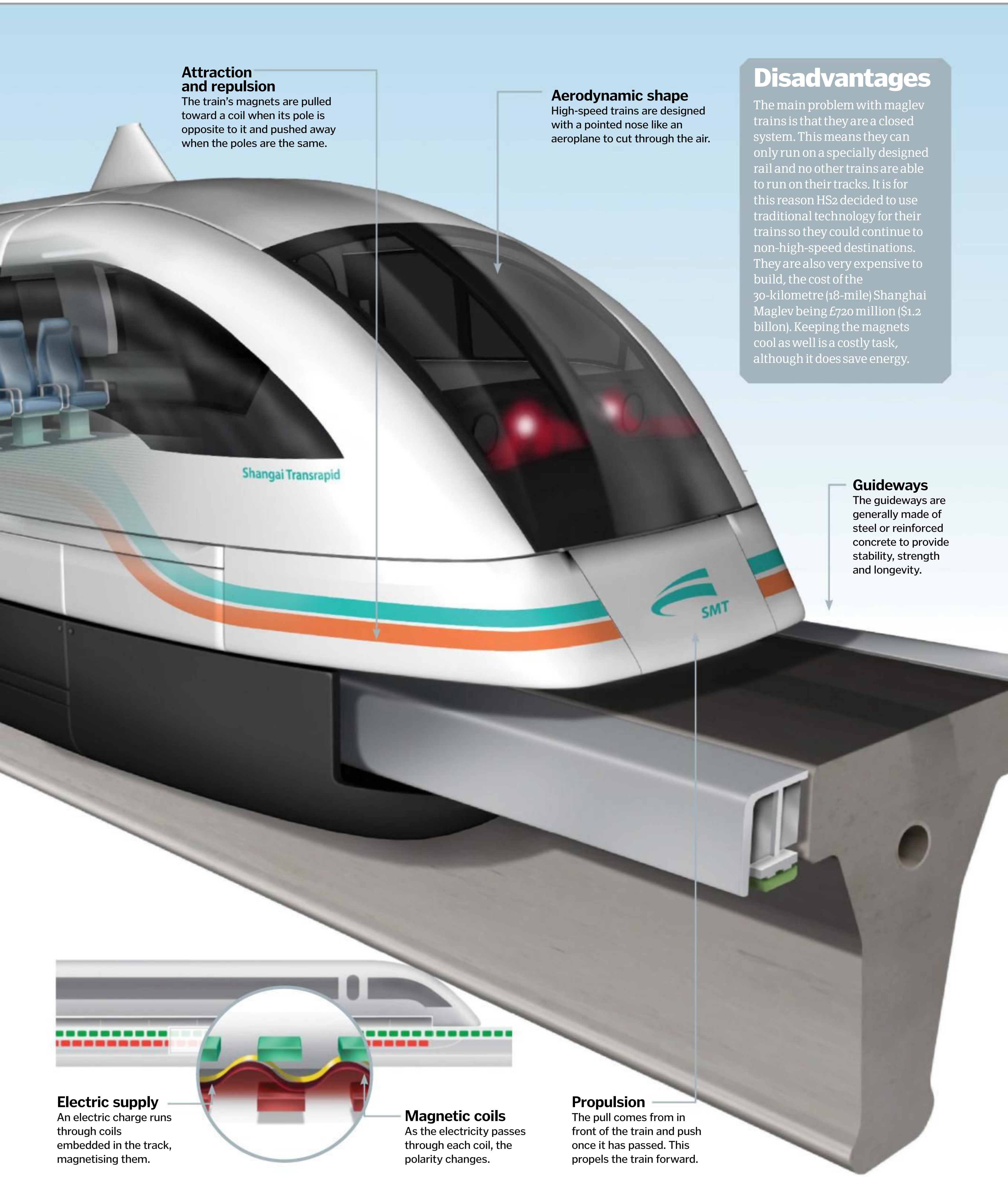
Cooling off
In some systems, the magnets can need to be super-cooled to prevent them overheating.

Inductrack
A cheaper system uses coils of copper wire arranged in such a way as to produce a constant magnetic field and the train's motion sends a current through the coils, propelling the train upward and forward.

Defying gravity
As it is not actually touching the track any more, the train has no friction to work against so can go faster.

Train magnets
Magnets are placed on the train, facing toward the coils.

Levitation magnets
Magnets placed underneath the track repulse the train's magnets, pushing the train up and away from the track.



Disadvantages

The main problem with maglev trains is that they are a closed system. This means they can only run on a specially designed rail and no other trains are able to run on their tracks. It is for this reason HS2 decided to use traditional technology for their trains so they could continue to non-high-speed destinations. They are also very expensive to build, the cost of the 30-kilometre (18-mile) Shanghai Maglev being £720 million ($1.2 billon). Keeping the magnets cool as well is a costly task, although it does save energy.

The secret behind reaching these incredible speeds is electromagnets. The maximum speed of conventional trains is limited by how powerful the engine is and how fast the wheels turn, but magnetic levitation (maglev) trains have neither of those drawbacks. This is mainly because they don't have engines or wheels! They hover between one and 10 centimetres (0.4 and four inches), suspended by magnets – both on the track and under the train – which repel each other. Magnetic coils ahead of the train are turned on, pulling the train forward with magnetic attraction. As the train reaches the coil, the magnet is turned off and the next one is turned on. The aerodynamic design of the train, together with the absence of friction from wheels and the strong electromagnetic forces, contribute to speeds of up to 430 kilometres (267 miles) per hour.

High-speed trains are constantly being developed and improved. In Germany, engineers have developed an electromagnetic suspension (EMS) system, called Transrapid. This utilises regular electromagnets and an additional set of magnets to guide the train. This prevents the carriages from rocking during turns by wrapping the Transrapid around the guideway, while the maglev sits on a cushion of air. It's reported that these EMS system trains are able to reach blistering speeds of 482 kilometres (300 miles) per hour.

In Japan, a new system currently being developed is called electrodynamic suspension. This involves the electromagnets being super-cooled and conserving energy, making the system much more efficient in terms of energy use, but is very expensive. Another downside to this system is that it needs to run on rubber tyres until it reaches a speed of 100 kilometres (62 miles) per hour, which causes unwanted friction.

The latest development to come out of the world of high-speed train travel is the Inductrack. This uses normal magnets that don't have to be super-cooled or electrically powered, but do involve the train using its own energy source to get up to speed and levitate before the magnets are able to pull it along. These magnets are made from a revolutionary neodymium-iron-boron alloy that dramatically increases the power of the magnetic field.

Who dreamt up magnetic trains?

The idea for magnetic levitation was first proposed in 1914 by Frenchman Emile Bachelet, who developed the rather brilliant idea of a series of magnets being turned on and off along a track to pull a train along. It didn't catch on back then, however, due to the spotty reliability of the electricity supply, but paved the way for the incredible, superfast technology we see today. The improvement in electric technology and the streamlined shapes of trains have allowed them to go faster and faster until they have reached the amazing speeds we see today in the Shanghai Maglev and Japanese Shinkansen.

Shanghai Maglev

The Shanghai Maglev is currently the world's fastest commuter train, reaching a top speed of an eye-watering 430 kilometres (267 miles) per hour, and that's just its operating speed. In testing it hit 500 kilometres (311 miles) per hour. It transports passengers along the Shanghai Maglev Line from Shanghai's Pudong Airport to the Longyang Road train station. The track is 30.5 kilometres (19 miles) long, with a journey time of just seven minutes and 20 seconds, as it travels at an average speed of 251 kilometres (156 miles) per hour. It has been running since 31 December 2002 and available to the public since 2004, so has held the record for the fastest commuter train in the world for an astonishing ten years, a monumental achievement in an industry where innovation and improvement seems to happen with incredible regularity.

Train stat-ion

430km/h

(267mph) Shanghai Maglev

(249mph) 2006 BAR Honda F1 car

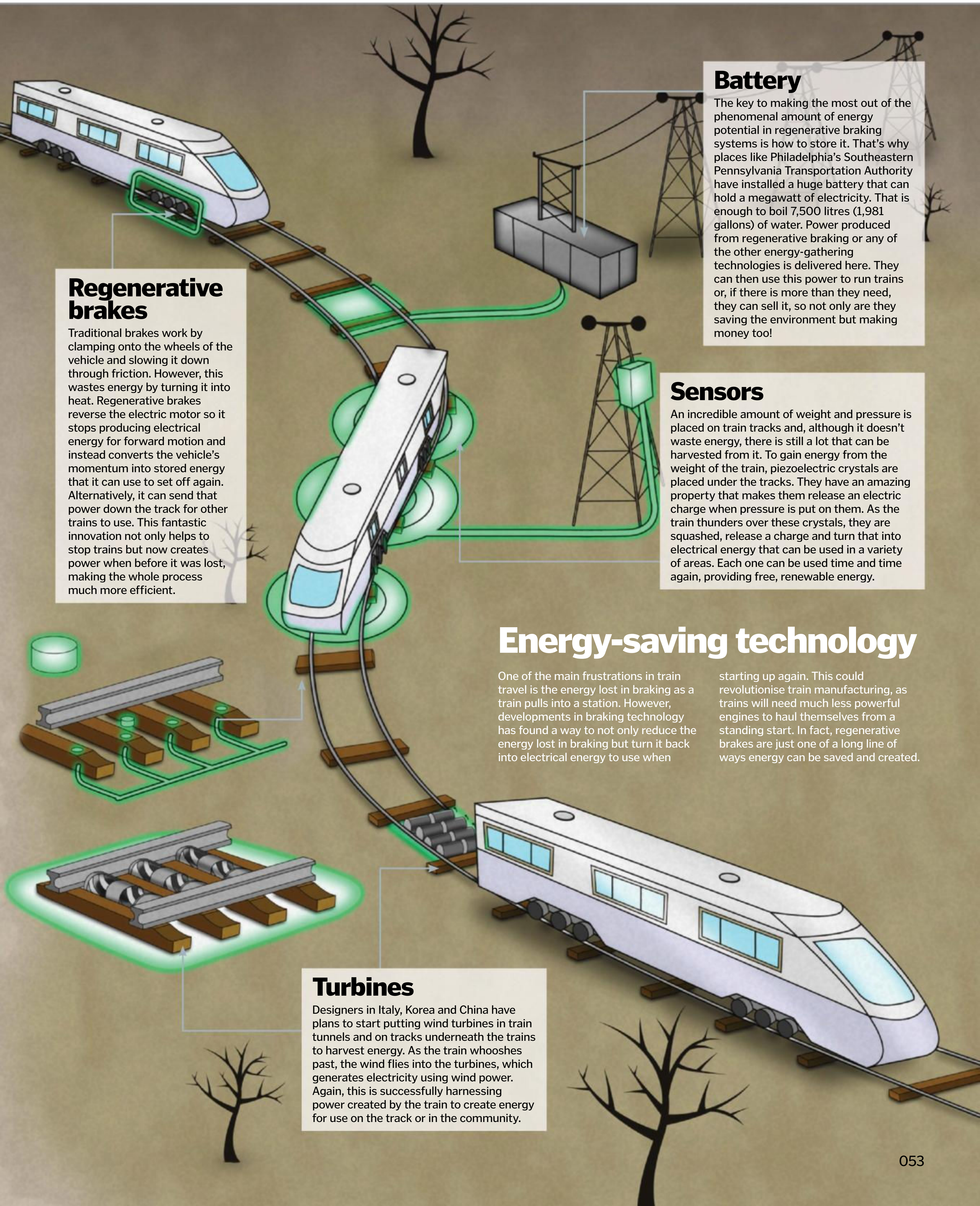
400km/h

111 HOURS

It would take the AGV Italo 111 hours to circle the equator

7 BILLION

Shinkansen trains have carried over seven billion passengers since 1964, that's the population of the entire planet. To date, there has not been a single accident



Energy-saving technology

One of the main frustrations in train travel is the energy lost in braking as a train pulls into a station. However, developments in braking technology has found a way to not only reduce the energy lost in braking but turn it back into electrical energy to use when starting up again. This could revolutionise train manufacturing, as trains will need much less powerful engines to haul themselves from a standing start. In fact, regenerative brakes are just one of a long line of ways energy can be saved and created.

Regenerative brakes

Traditional brakes work by clamping onto the wheels of the vehicle and slowing it down through friction. However, this wastes energy by turning it into heat. Regenerative brakes reverse the electric motor so it stops producing electrical energy for forward motion and instead converts the vehicle's momentum into stored energy that it can use to set off again. Alternatively, it can send that power down the track for other trains to use. This fantastic innovation not only helps to stop trains but now creates power when before it was lost, making the whole process much more efficient.

Battery

The key to making the most out of the phenomenal amount of energy potential in regenerative braking systems is how to store it. That's why places like Philadelphia's Southeastern Pennsylvania Transportation Authority have installed a huge battery that can hold a megawatt of electricity. That is enough to boil 7,500 litres (1,981 gallons) of water. Power produced from regenerative braking or any of the other energy-gathering technologies is delivered here. They can then use this power to run trains or, if there is more than they need, they can sell it, so not only are they saving the environment but making money too!

Sensors

An incredible amount of weight and pressure is placed on train tracks and, although it doesn't waste energy, there is still a lot that can be harvested from it. To gain energy from the weight of the train, piezoelectric crystals are placed under the tracks. They have an amazing property that makes them release an electric charge when pressure is put on them. As the train thunders over these crystals, they are squashed, release a charge and turn that into electrical energy that can be used in a variety of areas. Each one can be used time and time again, providing free, renewable energy.

Turbines

Designers in Italy, Korea and China have plans to start putting wind turbines in train tunnels and on tracks underneath the trains to harvest energy. As the train whooshes past, the wind flies into the turbines, which generates electricity using wind power. Again, this is successfully harnessing power created by the train to create energy for use on the track or in the community.

Eight incredible railways and trains

Ever since the first working railway was created in England over 400 years ago, in 1603, engines have evolved from primitive coal-powered mechanisms to super-efficient electric motors, meaning that they are able to travel much longer distances, both faster and with less resources for each unit of power. However, this has also meant that humans have had to get constantly more creative with the ways they overcome the challenges of travelling over and under – and sometimes straight through – tricky terrain. Through incredible and imaginative engineering, trains are now able to go over mountains, through hills and even under the sea. There are some lines that represent the dream of a life of luxury, while others are a daunting experience you probably wouldn't want to repeat in a hurry! But which are the most extreme of all?

The world's most dangerous railway

One of the most dangerous railways in history is the Chennai-Rameswaram railway line, which links mainland India with the island of Rameswaram. In 1964 the train, which still has to battle furious crosswinds, was hit by a huge tidal wave, knocking it off the tracks, killing all 115 people on board and demolishing part of the track. Although it has been rebuilt to be safer, it still crawls along the bridge at just over eight kilometres (five miles) per hour.

STAT

The Chennai-Rameswaram train travels at around the same speed as a swimming penguin

The world's longest

If you want to get across the world's largest country, you'll need the world's largest railway. Back in 1891, the Russians built the Trans-Siberian Railway. It spans over 9,200 kilometres (5,700 miles) and transports vital goods like oil, coal and grain. It was finished in 1916 and linked the inhospitable Siberia with the rest of Europe and Asia. Four kilometres (2.5 miles) of track were laid every day using stone to provide a stable surface in the swampy stretches and light metal and wood for the tracks themselves.

STAT

The Trans-Siberian Railway cost around seven times as much as the Golden Gate Bridge.

The world's highest

If you've got a head for heights, it could well be worth taking a trip on the world's highest railway, taking you from China to Tibet. It's called the Qinghai-Tibet railway and treats passengers to incredible views across the Qinghai-Tibetan Plateau. The Lhasa Express reaches a dizzying 5,072 metres (16,640 feet) high with an average elevation of over 4,000 metres (13,123 feet) above sea level. It also houses the world's highest railway station, the Tanggula, which sits at 5,068 metres (16,627 feet) above sea level.

STAT

The highest point of the Qinghai-Tibet railway is 262m (860ft) higher than Mont Blanc

The world's lowest

The Seikan railway tunnel connects Japan's Honshu and Hokkaido islands and sits 140 metres (460 feet) underneath the seabed, making it lower than any other railway. It was built between 1971 and 1988 and will be able to accommodate the superfast Shinkansen from 2016. The tunnel itself is nearly 54 kilometres (33.6 miles) long, with just under half of it below the seabed. 50 train journeys go through it every day, transporting people and freight between the two islands.

STAT

The tunnel used 85,000 tons of cement, enough to build a 10m (33ft)-wide wall higher than Burj Khalifa

The world's busiest train station

The Shinjuku Station in Tokyo is the world's busiest station, seeing an astonishing 3.64 million passengers board trains every day. There are 200 exits at the station in order to serve the huge numbers of people that come through its doors daily. A train arrives at one of its platforms every three seconds on average. The most popular line by far is the JR line, which takes nearly half the passengers who use the station.

STAT

More people use the Shinjuku Station every day than live in the country of Latvia

ON THE MAP

The world's longest railways

1 Trans-Siberian Railway
2 Orient Express
3 High-speed Shanghai to Guangzhou
4 Texas Eagle Chicago to LA
5 Toronto to Vancouver
6 Perth to Sydney

The world's longest station platform

In October 2013, work was completed on the longest train platform in the world. It measures a vast 1,366 metres (4,482 feet) and spans the length of the Gorakhpur railway station in India. When they built the station, they made sure they had the world's longest platform, eclipsing the previous record, which also happened to belong to a train station in India, by 294 metres (965 feet).

STAT

It would take Usain Bolt at least two minutes and 11 seconds to run the length of the Gorakhpur platform

The world's most famous train

If you're asked to name a train, you'll probably either say Thomas the Tank Engine or the Orient Express. As one is fictional, we'll focus on the one that travelled between Paris and Istanbul for 94 years, before being discontinued in 1977. It had four sleeping cars, each of which held ten compartments for snoozing in. It wasn't a technological marvel, but its romantic mystique kept it chugging away for the best part of a century.

STAT

The Orient Express took 60 hours to travel the 3,000km (1,864mi) between Paris and Istanbul

The world's oldest working train

Built by the UK-based Kitson, Thompson & Hewitson in 1855, the EIR-21 and EIR-22 steam locomotives are still running, transporting passengers between the cities of Alwar and New Delhi in India. Weighing in at a hefty 26 tons, each train can deliver 97 kilowatts (130 horsepower) and can reach 40 kilometres (25 miles) per hour. That's not bad for an almost 160-year duo of steam locomotives…

STAT

In the 159 years since EIR-21 and EIR-22 were built, Britain has had six different monarchs

HOW IT WORKS

AIR

A look inside the giants of the sky

© NASA; Lockheed Martin

"Eradicating sonic booms is key to supersonic jets"


70

© Airbus


82


66

© Boeing

© Solar Impulse


72


58

© Oscar Viñals

SUPER JETS

THE TECH POWERING PLANES OF TOMORROW

■ VERTICAL TAKEOFFS ■ WINDOWLESS DESIGN ■ SELF-HEALING TECHNOLOGY

On 1 January 1914, the world was changed forever when the first commercial flight took to the skies. It flew between the cities of St Petersburg and Tampa in the state of Florida in the United States, lasting a total of 23 minutes and covering a distance of 33.8 kilometres (21 miles).

This landmark event came 11 years after the famous Wright brothers' first powered flight, and marked the first time someone paid to be a passenger on an aircraft. The plane was the boat-like Benoist XIV, which only had room for the pilot and the auction-winning bidder, who coughed up a healthy $400 for the experience. That would be over $9,500 (£5,850) in today's estimated currency value.

Today, people are likely to pay over 100 times that initial amount for a ticket on a suborbital flight. These space planes will take their passengers into orbit, cutting the time from London to the US west coast down to an astonishing 60 minutes. However, it's not just the passengers that are getting a boost. Plans are well under way for smartplanes that can sense when they've got a problem and even heal themselves mid-flight.

The last 100 years have seen startling improvements in commercial aeroplane technology, such as enormous double-decker jets that can carry up to 853 passengers in a single haul, planes that can circle the world in less than two days and, of course, the legendary Concorde that took over 2.5 million people through the sound barrier.

Over the next few pages, we look to the next century of sparkling innovation to see what the aircraft of the future might look like. Commercial flight has come a million miles from that first wooden biplane journey, so buckle up, put your tray into the upright position and please stay seated for the duration of your journey.

SKY WHALE

Is this three-storey concept vehicle the future of travel?

The Airbus A380 currently holds the title for the biggest passenger plane, but that could all change. Called Sky Whale, this concept aeroplane would have a wingspan of 88 metres (289 feet), compared to the A380's 80 metres (262 feet). It would seat 755 passengers, making it economically viable for airlines. The Sky Whale would be able to fly further without refuelling thanks to a double fuselage, and solar cells on the wings would harness power from the Sun. Designed by Oscar Viñals, the aircraft also boasts innovative features such as tilting engines for near-vertical takeoffs. Visit **www.behance.net/ovisdesign** for more.

Design: Oscar Viñals

The engines rotate up to 45 degrees for a vertical takeoff

755 Seats on three levels

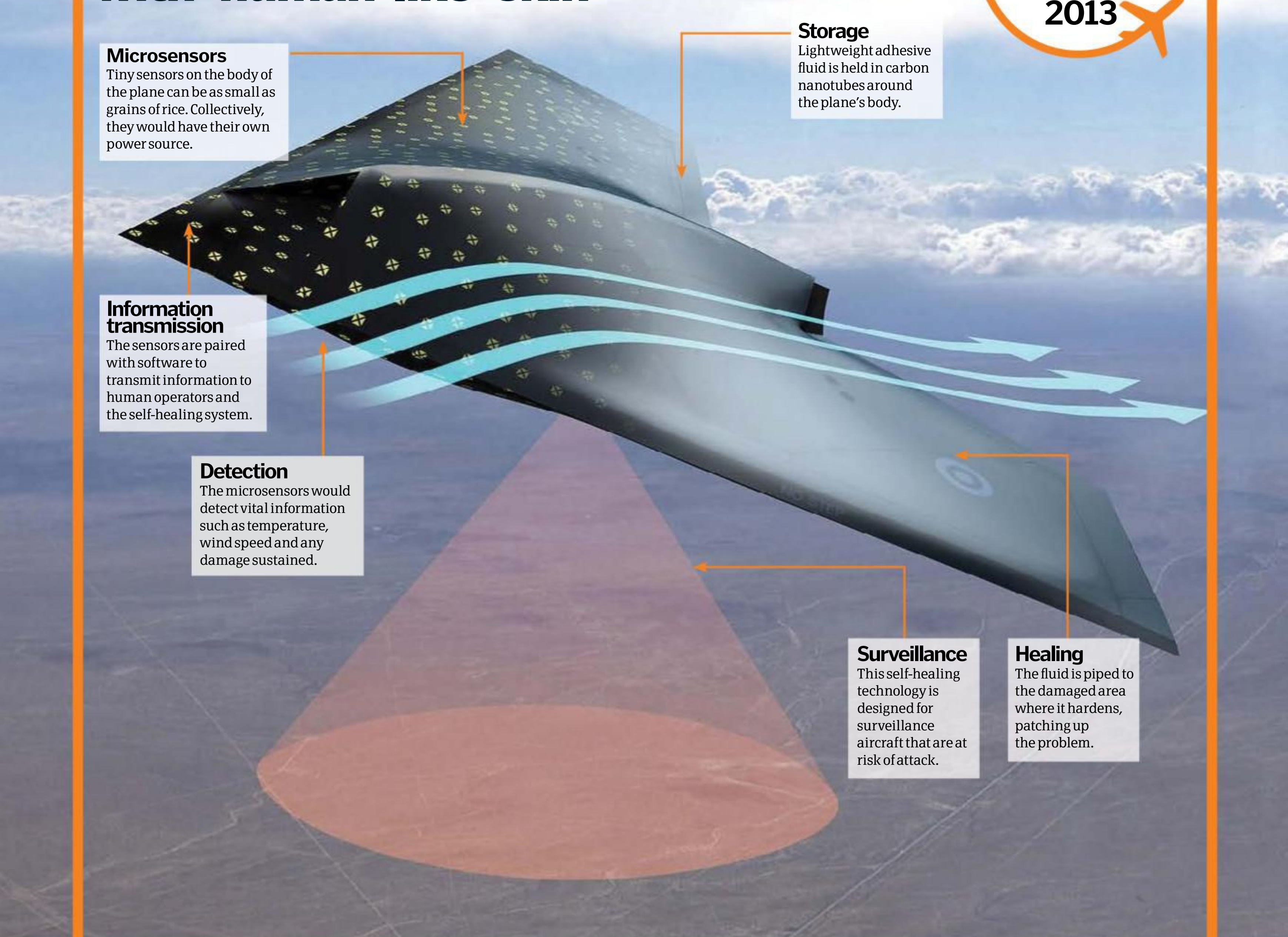
The Sky Whale is a radical reimagining of the commercial aeroplane

THE SURVIVOR

Design: BAE Systems

Self-repairing plane technology with 'human-like' skin

£117m Research costs in 2013



Movies like *The Terminator* may have warned us not to create technology that can heal itself, but the folks at BAE Systems decided to press on regardless. The UK company has unveiled futuristic designs that could revolutionise the method – and speed – that planes are repaired by 2040.

The aircraft's body would be covered in tens of thousands of microsensors that detect wind speed, temperature and any damage sustained. The craft would be able to heal itself in mid-air thanks to a grid of carbon nanotubes that hold a lightweight adhesive fluid. This would be released to the damaged area and quickly harden – like blood forming a scab on a cut – enabling the craft to continue its flight.

This advanced use of materials would create an extremely hardy jet capable of entering the most dangerous of scenarios to complete vital missions, according to a BAE Systems spokesman. They are calling it The Survivor, and that's not the only technology the company believes could be incorporated in military aircraft in the future. Another type of jet, known as The Transformer, would combine smaller sub-aircraft during travel and then split off. This would increase range and save fuel by reducing drag when they fly together.

Despite edging us ever closer to Skynet, this technology is hugely exciting for the aviation industry as smart planes would send maintenance costs and times plummeting, leaving us much more time to plan how to prevent them from rising up against us!

SMARTER SKIES

Design: Airbus

The most energy-efficient plane on the planet

Airbus has always been at the forefront of aviation technology and its futuristic Smarter Skies concept aims to be more efficient and eco-friendly. Here are a few ways in which it's hoping to make future air travel better for passengers and the environment by 2050.

9mn Tons of fuel that could be saved

Learn more

To have a good look around the most futuristic cabin ever, download The Future By Airbus app for free from iTunes. It gives you a virtual tour of the flight you could be catching in around 35 years.

ECO-CLIMB

Electromagnetic motors built into the runway would save fuel and reduce noise pollution. They could launch the plane into the air on take-off and capture it as it lands, slowing it down safely. This would save fuel by removing the need for heavy landing gear, but would require every airport to have the same system.

CONCEPT CABIN

Airbus is looking to do away with cramped seats, narrow aisles and class warfare. Instead, planes will be split into zones, such as a relaxation zone, an interaction zone and a smart tech zone. The latter could hold seats made of materials that have a 'memory', morphing to each passenger's body shape.

BETTER TOGETHER

Birds flying in their V formation reduce drag by up to 65 per cent. Airbus is proposing planes on popular routes could club together and fly in formation, reducing fuel burn by ten to 12 per cent. That could save over 10,000 litres (2,640 gallons) of fuel on a journey between London and New York.

IXION **Design:** Technicon

Panoramic views that bring the outside in

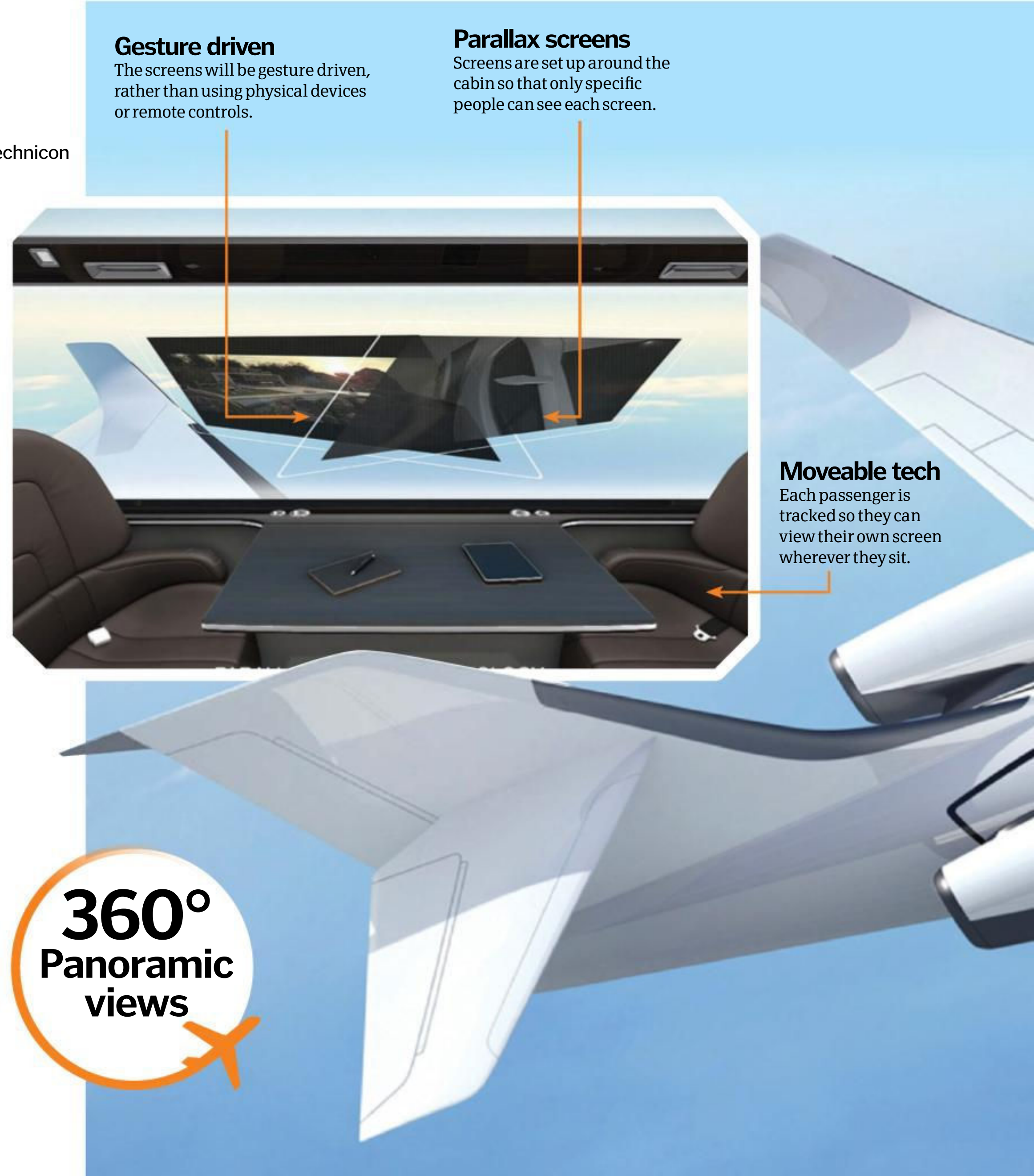
Apart from using newer materials and streamlining, actual aeroplane design has changed very little over the years. However, Technicon Design is an international company trying to change all that with its concept of a windowless jet called the IXION.

Gareth Davies, design director at Technicon Design, explains his vision for future planes: "Windows are complicated things to put into aeroplanes. Each window can add 15 kilograms (33 pounds) to the overall weight and they're not aerodynamic. Our plan is to remove the windows and fit 4K HD cameras to the wings and body that can display images of whatever's outside onto flexible OLED screens inside the plane."

This would give an uninterrupted panoramic view from the inside, while reducing weight and simplifying construction. A myriad of potential cabin moods and themes would be opened up: "You'll be able to control what is displayed on the screens from your smartphone." This could result in a future where passengers travelling over a featureless ocean could be treated to sights like the New York skyline, a desert or even Godzilla taking on downtown Tokyo.

If you don't fancy looking at the same view as everyone else, the concept also suggests parallax screens that can only be seen by the person sitting in a particular seat. To create a truly flexible seating arrangement, passengers would be tracked so their screen follows them to whatever seat they sit in.

Solar panels would also be employed to power internal electronics. This would generate alternative power for the low-voltage systems on board when the engines are idle and save five per cent of the total fuel used. The designs challenge conventional thinking on every level. "We wanted to imagine a possible next step forward", he continues. "The first stage in any innovation is imagination."



Windowless design

The idea behind the windowless design has two main advantages. First, it makes the plane easier to build and more streamlined. Second, and more exciting, is it lets you do crazy and cool things like the image shown here on the right.

4K HD cameras mounted on the wings and body of the plane will be connected to OLED panels in the wall, which will display the outside images in real-time. This is done in the same way as a video camera can display images on a TV using an HDMI cable. The video is taken, sent down a cable to the screens where they are enlarged and reappear as a high-definition live feed.

The screens can also be operated by the passengers, where gesture controls will allow you to make presentations to a group, hold video conferences or watch a film on the wall of the plane. Welcome to the future!

Smartphone enabled
Images from a smartphone can also be displayed on the screens.

Bringing the outside inside
The images from the external cameras will be displayed on OLED screens inside the plane.

Solar panels
Internal electronics will be powered by solar panels on the plane's body.

OLED screens
Thin, flexible plastic screens replace the traditional porthole windows, giving passengers panoramic views.

Windowless body
The lack of windows makes the IXION easier to build, lighter and more streamlined.

Cameras
4K HD cameras will take real-time video of the world outside the plane.

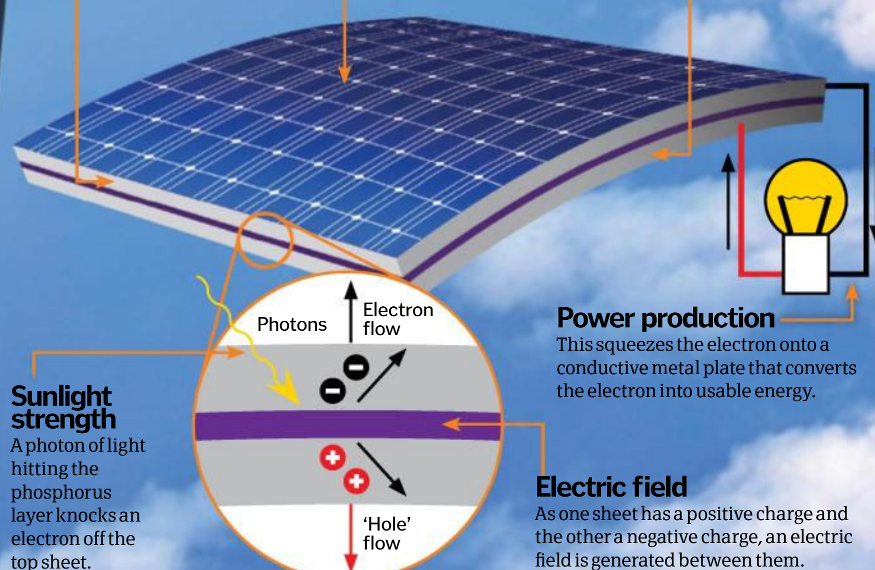
Passengers could be treated to a panoramic view of the world outside their plane. Would you dare look down?

Solar-powered planes
How planes harness the Sun's energy

Silicon sandwich
A solar panel is made up of two sheets of silicon, split up into lots of photovoltaic cells.

Top layer
The top layer is coated with phosphorus, which increases the number of free electrons on that side.

Bottom layer
This layer will be coated with boron, which decreases the number of free electrons.



Power production
This squeezes the electron onto a conductive metal plate that converts the electron into usable energy.

Sunlight strength
A photon of light hitting the phosphorus layer knocks an electron off the top sheet.

Electric field
As one sheet has a positive charge and the other a negative charge, an electric field is generated between them.

SPACE PLANES

These out-of-this-world vehicles are boldly going where no commuter has gone before

Travelling faster than the speed of sound, Concorde made it from London to New York in around three hours. However, that's sloth-like compared to the space plane aiming to travel from Europe to Australia in half that time.

That craft is SpaceLiner, being developed the German Aerospace Center. This 83.5-metre (274-foot) long craft could carry up to 100 passengers up to 80 kilometres (50 miles) into the air, gliding in sub-orbit at over 20 times the speed of sound. It would be delivered into the higher layers of our atmosphere by LOX/LH_2 (liquid oxygen and liquid hydrogen) rockets before disengaging at nearly four kilometres (2.5 miles) per second. This would allow it to reach Australia from Europe in as little as 90 minutes from takeoff to landing.

Also on the horizon are the Virgin Galactic and Skylon space planes, which are looking to go directly up from – rather than around – the Earth. Virgin Galactic's SpaceShipTwo will be launched from a jet-powered plane. It will take passengers into space for a few minutes before returning to Earth. Skylon, on the other hand, is an unmanned, reusable space plane designed to carry 15 tonnes of cargo into outer space and return. This would make it much easier and cheaper for private companies to send cargo into space for use on satellites and space stations.

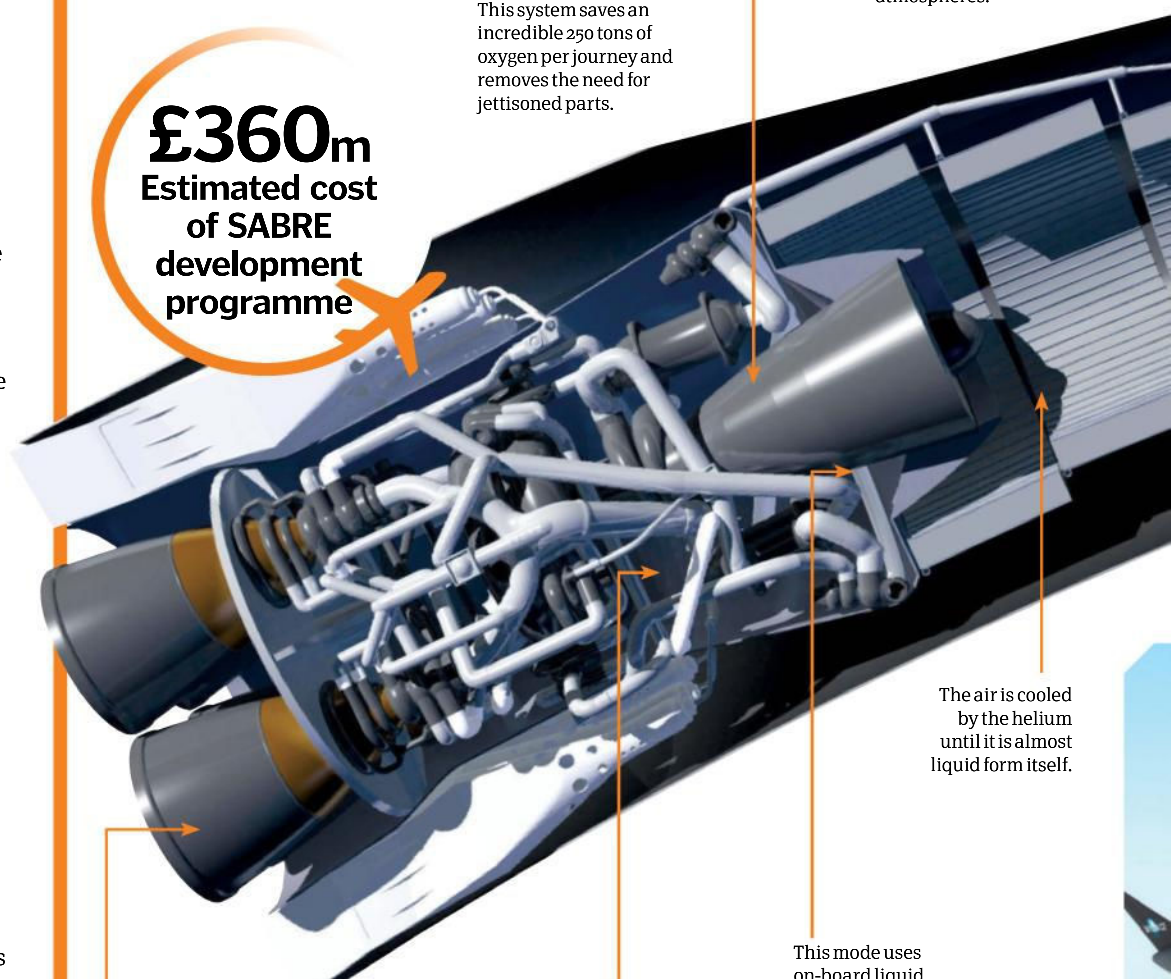
They used to say the sky's the limit, but the next generation of passenger and cargo planes have shown that it's only the beginning.

SKYLON

Design: Reaction Engines Ltd

Inside the SABRE engine

What is powering this new, reusable rocket Skylon?



VIRGIN GALACTIC

Design: Scaled Composites

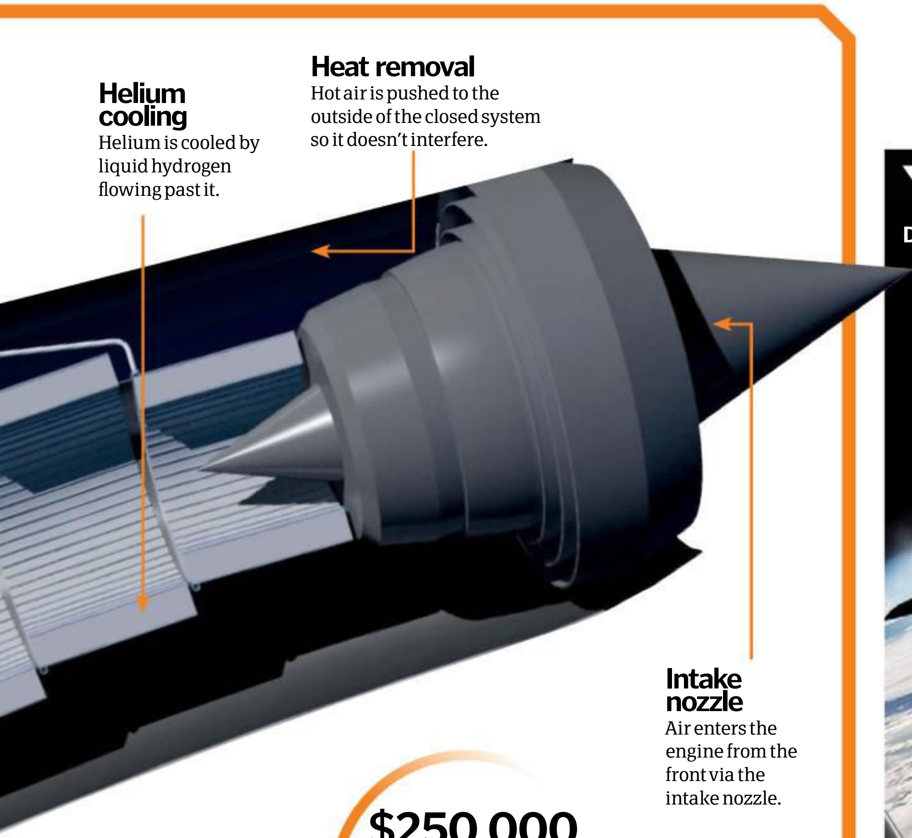
Richard Branson announced to the world in 2004 that he would be sending tourists into space, making Virgin Galactic the first commercial space plane. However, despite original plans to launch a flight in 2007, Virgin Galactic is yet to take its first batch of space tourists into the Solar System.

The ship will be carried to a height of 15,240 metres (50,000 feet) by the support craft WhiteKnightTwo. The crafts will detach and the passenger ship will fire its rockets to take its passengers out of the Earth's atmosphere and into space.

After four to five minutes it will re-enter the Earth's atmosphere, coming back to land on the runway at its New Mexico base.

The technical and logistical hitches that have set the programme back are being resolved, with the Federal Aviation Administration (FAA) clearance a major hurdle overcome in May 2014. Hopefully, the journey to outside our atmosphere is just around the corner.

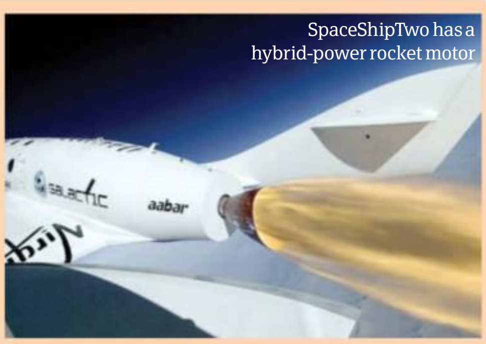

The Virgin Galactic team standing in front of SpaceShipTwo



$250,000
Virgin Galactic ticket cost

What the Skylon will look like when it soars above our skies

SpaceShipTwo has already flown several test flights



SpaceShipTwo has a hybrid-power rocket motor

SPACELINER

Design: German Aerospace Center

A concept drawing of what the SpaceLiner will look like

London to Sydney in 90 minutes

We spoke to Olga Trivailo who works at the German Aerospace Center to explain what is in store for future long-distance fliers

How exactly will the proposed SpaceLiner work?
It will use standard rocket technology such as liquid hydrogen and oxygen-fuelled rockets to accelerate to Mach 25. Once it is at 70 to 80 kilometres (43.5 to 50 miles) high, the booster will detach and return to the launch site. The craft will then glide all the way to its destination.

Does the lack of gravity or wind resistance play a part in its speed?
No. It cuts travelling times so much purely because it is travelling so fast from the rocket boost. It needs to go that high to go that fast so it can get the full benefit from the rocket's speed.

What sets the SpaceLiner apart from other flight options?
The reusability is a major part in the SpaceLiner programme. The fact that we will be able to reuse both parts of the rocket makes it much more viable as a business.

What kind of market are you looking at then?
Initially we want to target the business-class passengers who need to travel long distances and want to cut down their time. A trip to Australia from Europe [currently] takes over 24 hours when you count transfer time and when you get there, you just don't feel human. I feel this will really benefit mankind as SpaceLiner could also be used to transport time-sensitive cargo, such as organs.

Will everyone be able to use it, or just the extremely physically fit?
Anyone who is reasonably healthy can travel on it. At take-off you would experience at most 2.5 g. To put this into perspective, a normal flight could create up to 1.25 g and some roller coasters experience 5 g.

When are we expecting it to come into service?
If we're being realistic, in around 30 to 35 years. We need that time because, even though the rocket technology is there, we need to make it safe for the public to use. This means finding materials that can deal with the heat of the Earth's atmosphere and making the passenger pod capable of turning into an emergency escape pod in the unlikely event of an accident.

Boeing 787 Dreamliner

This jetliner has transformed the commercial airliner industry, boasting significantly improved fuel economy and a host of next-gen features. We take a closer look…

At first glance the Boeing 787 Dreamliner appears to be nothing special. A new mid-sized jetliner that through its conventional design, standard power output and modest maximum range seems to, for the most part, blend in with the crowd. Just another commercial passenger jet introduced to a market hit severely by the worldwide recession. A multimillion pound piece of technology that changes nothing. But if you believe that, then you couldn't be more wrong…

That is because, as is common with most groundbreaking new technologies and ideas, the devil is in the details. Indeed, the 787 is arguably a slice of the future today, both literally (its service life is predicted to extend up to 2028) and metaphorically. The latter comes courtesy of it being the first aircraft to be designed within a mantra of efficiency over all else. That's not to downplay its numerous improvements and technological advancements in any way – this is one of the most complex jetliners currently in operation – but in the present financial climate and arguably one that will affect the industry for years to come, this greener, cheaper and more accommodating aircraft is laying down a roadmap that others can follow. The evidence for this? How about worldwide orders of 982 planes from 58 operators to the tune of over £100 ($169) billion?

So how is the 787 turning the dream of cheaper, more efficient air travel into a reality? The simple answer is a direct 20 per cent saving on both fuel usage and outputted emissions. The long answer is a little more complicated.

The key to the super-high performance granted by the Dreamliner lies in its adoption of a suite of new technologies and materials. Composite materials (ie carbon-fibre/reinforced carbon-fibre plastics) make up 50 per cent of the primary structure of the 787, which include both the fuselage and the wings. These are lighter, stronger and more versatile than traditional pure-metal offerings. Indeed, when this model is compared against the Dreamliner's predecessor, the 777 – read: a mere 12 per cent composite materials and over 50 per cent aluminium – you begin to grasp what a game-changer this vehicle is to the jetliner industry.

The new materials have been partnered with a completely revisited build process, which allows each Dreamliner to be produced from fewer aluminium sheets, less fasteners (an 80 per cent reduction on the 777) and simpler drill schematics – the latter allowing a 787 to have fewer than 10,000 holes drilled in its fuselage (the 747 needed over 1 million). This saves on production costs, assembly time and streamlines the build, reducing potential points of failure, while increasing aerodynamic efficiency. In addition, more than 60 miles of copper wiring has been eliminated from the new model, again saving weight, plus streamlining the electrical

© Boeing

More than 50 companies have worked on the 787, each connected virtually at 135 sites worldwide

© Boeing

787 cabin layouts can be split into one of three configurations, prioritising capacity or class divisions

© Boeing

The statistics…

Boeing 787 Dreamliner

Crew: 2

Length: 57m (186ft)

Wingspan: 60m (197ft)

Height: 17m (56ft)

Max weight: 228,000kg (502,500lb)

Cruise speed: 1,041km/h (647mph)

Max range: 15,200km (9,440mi)

Max altitude: 13,100m (43,000ft)

Powerplant: 2 x General Electric GEnx / Rolls-Royce Trent 1000

infrastructure. Talking of electronics, the Dreamliner has been designed with a state-of-the-art, fully electronic architecture, which through the replacement of all bleed air and hydraulic power sources with electrically powered compressors and pumps, extracts as much as 35 per cent less power from its engines at any one time. Further, a new electrothermal wing ice protection system – with moderate heater mats located on wing slats – improves de-icing levels and consistency significantly, again boosting aerodynamic performance. Wing lift performance is also improved thanks to the adoption of raked wingtips, which reduce the thrust needed by the engines.

These efficiencies combine with the heart of the Dreamliner: its twin next-generation, high-bypass turbofan engines. Two engine models are used on the 787 – both the General Electric GEnx and Rolls-Royce Trent 1000 – each delivering a maximum thrust of 280 kilonewtons (64,000 pounds force) and a cruise speed of Mach 0.85 (1,041 kilometres/647 miles per hour). Both engines are designed with lightweight composite blades, a swept-back fan and small-diameter hub to maximise airflow and high-pressure ratio – the latter, when complemented by contra-rotating spools, improving efficiency significantly. Finally, both engines are compatible with the Dreamliner's noise-reducing nacelles, duct covers and air-inlets. Indeed, the engines are so advanced that they are considered to be a two-generation improvement over any other commercial passenger jet.

As such, contrary to initial appearances, the Dreamliner is really a wolf in sheep's clothing, delivering standard-bearing improvements, along with a vast list of incremental ones – including energy-saving LED-only lighting – that make it one of the most advanced and future-proofed jets in our skies today. And you know what is most exciting? Judging by Boeing's current substantial backlog of sales, there is a high probability that you will be flying on one of these mighty machines yourself in the very-near future.

A General Electric GEnx high-bypass turbofan jet engine, one of two used on the Dreamliner

© Oliver Cleynen

Anatomy of the Dreamliner

Breaking down a Boeing 787 to see how it outpaces, out-specs and outmanoeuvres the competition

© Boeing

© Boeing

Cockpit

The Dreamliner's state-of-the-art cockpit is fitted with Honeywell and Rockwell Collins avionics, which include a dual heads-up guidance system. The electrical power conversion system and standby flight display is supplied by Thales and an avionics full-duplex switched ethernet (AFDX) connection transmits data between the flight deck and aircraft systems.

Cargo bay

The standard 787 – referred to as the 787-8 – has a cargo bay capacity of 125m³ (4,400ft³) and a max takeoff weight of 227,930kg (503,000lb). The larger variant – referred to as the 787-9 – has a cargo bay capacity of 153m³ (5,400ft³) and a max takeoff weight of 247,208kg (545,000lb).

Electronics

The 787 features a host of LCD multifunction displays throughout the flight deck. In addition, passengers have access to an entertainment system based on the Android OS, with Panasonic-built touchscreen displays delivering music, movies and television in-flight.

The first completed Dreamliner was delivered to All Nippon Airways in 2011

© Boeing

Flight systems

The 787 replaces all bleed air and hydraulic power sources with electrically powered compressors and pumps. It is also installed with a new wing ice protection system that uses electrothermal heater mats on its wing slats to mitigate ice buildup. An automatic gust alleviation system reduces the effects of turbulence too.

Wings

The 787 Dreamliner's wings are manufactured by Mitsubishi Heavy Industries in Japan and feature raked wingtips. The raked tips' primary purpose is to improve climb performance and, as a direct consequence, fuel economy.

Engines

Two engine models are compatible with the Dreamliner: twin General Electric GEnx or Rolls-Royce Trent turbofans. Both models produce 280kN (64,000lbf) and grant the 787 a cruising speed of 1,041km/h (647mph). They are also compatible with the jet's noise-reducing nacelles, duct covers and exhaust rims.

Evolution of the jetliner

We select some of the high points in the development of the commercial jetliner

1945 Vickers VC.1 Viking
A British short-range airliner derived from the Wellington bomber, the Viking was the first pure jet transport aircraft.

1952 DH-106 Comet
The Comet was the world's first commercial jet airliner to reach production. It was developed by the de Havilland company in England.

1955 SE-210 Caravelle
The most successful first-generation jetliner, the Caravelle was sold en masse throughout Europe and America. It was built by French company Sud Aviation.

1958 Boeing 707-120
The first production model of the now-widespread 707 series, the 707-120 set a new benchmark for passenger aircraft.

1961 Convair 990
A good example of a narrow-body jetliner, the 990 offered faster speeds and greater passenger-holding capacity.

1976 Aérospatiale-BAC Concorde
A standout development in the second generation of jetliners, the Concorde delivered supersonic, transatlantic flight – something unrivalled even to this day.

© Boeing

A stand-up, fully stocked bar is available on each 787

Cabin
The standard 787 is designed to seat 242 passengers across a three-class arrangement, with 182 seats in economy, 44 seats in business and 16 seats in first. Cabin interior width rests at 5.5m (18ft) and on either side is lined with a series of 27 x 47cm (11 x 19in) auto-dimming windows.

Amenities
When on board passengers are offered roomier seats (across all classes), larger storage bins, manually dimmable windows, a stand-up bar, gender-specific lavatories and an on-demand entertainment system. First-class passengers receive a complimentary in-flight meal and, on international flights, fully reclinable seats for sleeping.

Fuselage
The 787 is constructed from 80 per cent composite materials (carbon fibre and carbon-fibre reinforced plastic) by volume. In terms of weight, 50 per cent of the materials are composite, 20 per cent aluminium, 15 per cent titanium, 10 per cent steel and 5 per cent other.

© Boeing

Compatibility
The 787 Dreamliner is designed to be compatible with existing airport layout and taxiing setups. As such the 787 has an effective steering angle of 65 degrees, allowing it to rotate fully within a 42m (138ft)-wide runway. It also has a 32m (100ft) tyre edge-to-turn centre ratio.

© Boeing

1986 Fokker 100
The Fokker 100 was a short-haul specialist that carried up to 100 passengers. Domestic and short-range international flights were its remit.

1994 Boeing 777
The first computer-designed commercial jetliner, the 777 delivered a vast 300-seat capacity and range (17,370km/10,793mi). It became a mainstay of airlines worldwide.

2005 Airbus A380
Since its launch in 2005 the Airbus has been the largest passenger aircraft in the world. The A380 has two decks and, when specced out for all economy-class seating, can carry 853 passengers.

2011 Boeing 787 Dreamliner
The most fuel-efficient jetliner of its class, the 787 has been designed to reduce the cost of air travel, while delivering a range of next-gen tech.

2x © Boeing

Train to gain

Boeing has gone the extra mile to produce a complete package with the 787 Dreamliner, offering state-of-the-art simulation facilities for pilots to get up to speed

Potential 787 pilots can utilise Boeing's revolutionary full-flight simulator to train for real-world flights and specific context-sensitive scenarios. Currently there are eight 787 training suites at five Boeing campuses worldwide, located from Seattle through to Tokyo, Singapore, Shanghai and on to London Gatwick. The simulators, which are produced by French electronic systems company Thales, include dual heads-up displays (HUDs) and electronic flight bags (EFBs), and are designed to train pilots to become proficient in visual manoeuvres, the instrument landing system (ILS) and non-ILS approaches. Further, missed approaches using integrated specialist navigation, non-standard procedures with emphasis on those affecting handling characteristics, plus wind shear and rejected takeoff training can also be undertaken.

All of the training simulators are approved by the US Federal Aviation Administration (FAA), making them officially some of the most advanced training suites around right now.

Pilots and potential pilots can train at eight simulators worldwide

Airbus

At around $300 million each, it's the largest and most expensive passenger plane in the world. Yet the Airbus A380 is also supposed to be the most fuel efficient, noise reducing and eco-friendly people carrier in its class

The Rolls-Royce manufactured engines will keep the A380 in the sky

At the controls of the world's largest jet

Built in France, Germany, Spain and the UK and assembled in Toulouse, the A380 is a truly pan-European project. It is an attempt not just to revolutionise long haul flying but aircraft design and construction itself. From the carbon fibre reinforced plastic that makes up roughly 25 per cent of the structure, to its unique wide-body fuselage, the A380 has been designed to set new standards, so much so that even major airports like Heathrow will need a multi-million pound refit before they will be able to handle it. With an operating range of 15,200km (enough to fly non-stop from New York to Hong Kong) and a cruising speed of Mach 0.85 (around 560mph), the A380 will open up new routes and possibilities for international travel, but the real breakthrough is in its sheer size and ambition.

Whichever way you look at it, the Airbus A380 is massive. With a wingspan of nearly 262 feet (that's 1 ¾ football pitches) and a maximum takeoff weight of 1.2 million points, it affords 50 per cent more floor space than its nearest rivals. The A380 has many potential configurations, from its maximum passenger capacity of 853 passengers to the current layout of 555 passengers in three classes, which is still significantly more than the 416 that can be carried by the current long-haul frontrunner, the Boeing 747-400.

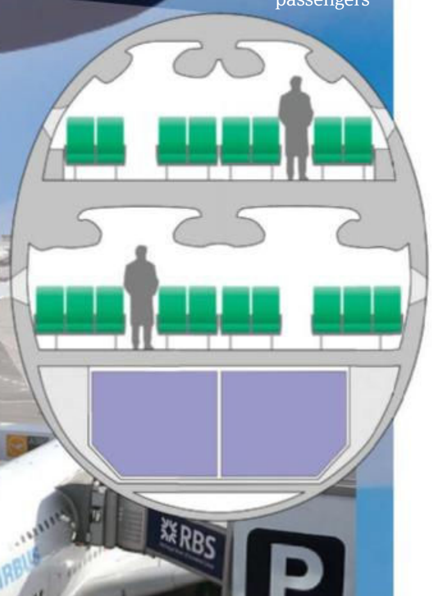
But what about claims that this long-haul behemoth is actually environmentally friendly, something many green campaigners maintain is a contradiction in terms? As always, there is truth on both sides. As one of only a handful of commercial aircraft to adhere to stringent ISO 14001 corporate certification, the A380 is at the forefront of environmental aircraft design. With 33 per cent more seats than a 747-400, it carries more passengers while consuming less than three litres of fuel per passenger over 100km, roughly equivalent to a family car and 17 per cent less than a 747. Meanwhile the high-efficiency engines developed by Rolls-Royce, General Electric and Pratt & Whitney produce only about 75g of CO_2 per passenger kilometre, which is also less than a 747 (although Boeing would maintain not less than its own planned successor, the 787 'Dreamliner'). On the other hand, those figures are dependent on flying at near maximum capacity, which few of the A380's initial buyers are expecting for several years.

Meanwhile, environmentalists argue that the combination of the millions of passengers who have already used the A380, the commercial pressure to fill all those extra seats and the airport congestion and urbanisation caused, merely compounds the environmental damage created by any expansion in long haul flying. Either way, people are going to be discussing the pros and cons of this aerial juggernaut for decades to come.

A380

The luxurious interior can make you forget you're in a plane!

The two-storey cabins can hold up to 853 passengers



The statistics...

Airbus A380

Weight (empty): 610,700lbs

Length: 73m (240ft)

Wingspan: 79.75m (261.8ft)

Maximum number of passengers: 853 (currently configured for a max 555)

Max speed (at cruise altitude): 945km/h, 587mph, 510 knots

Maximum payload : 90,800kg (200,000lbs)

The A380 seen flying over Broughton, where the wings are built

Developing the A380

Although the development of the A3XX series was only formally announced in 1994, it had been on various drawing boards since back in 1988, initially as part of a top secret Ultra High Capacity Airliner project designed to break the dominance of the mighty Boeing 747. During its complex genesis it went through phases of being a joint Very Large Commercial Transport (VLCT) study with Boeing and a revolutionary 'flying wing' design before assuming the oval double-deck form it boasts today. This was finally agreed upon because it was deemed to provide more passenger volume than a traditional single-deck design as proving more cost effective than the VLCT study and Boeing's brand new 787.

Built in 16 manufacturing sites across Europe, constructing the A380 is a logistical nightmare. The front and rear fuselage sections have to be shipped from Hamburg to the UK while the wings are built in Bristol and Broughton and transported by barge to Mostyn. Meanwhile, the belly and tail sections are built in Cádiz and then taken to Bordeaux. Eventually all these parts must be transported by barge, road and rail to Toulouse where the aircraft is pieced together. Along the way, roads need to be widened, cargo ships refitted and barges specially built to accommodate the parts. The finished aircraft must then be flown back to Hamburg for painting and any other finishing touches.

It's not just logistics that have proven problematic. The A380's development coincided first with a financial crisis in the Far East and more recently the global economic downturn, affecting both development cost and potential markets. Originally scheduled to take eight years and $8.8 billion to develop, it has so far cost an estimated $15 billion, with development of the freight version, the A380-800F, first postponed and then suspended. Meanwhile the break-even point for the passenger version, the A380-800, has risen from 270 to over 420 units, of which 200 have been ordered and around 20 delivered, most recently to the Saudi Arabian airline, Saudia. The A380-800 made its maiden flight on 27 April 2005 from Toulouse and its first commercial flight from Singapore to Sydney on 25 October 2007.

Solar-powered aircraft

The flying machines that are fuelled only by the Sun

As the search for renewable and carbon-neutral forms of energy intensifies, solar energy is leading the way for aircraft. One aircraft soaring through boundaries is the Solar Impulse 2. This incredible machine has just finished a non-stop round-the-world trip powered only by the Sun. It used its 72-metre- (236-foot-) wide wings, each of which carrying over 8,500 solar cells, which were used to power four electric motors and four lithium batteries. Despite this astonishing wingspan, the entire aircraft only weighs 2,300 kilograms (5,071 pounds) – about as heavy as a large great white shark.

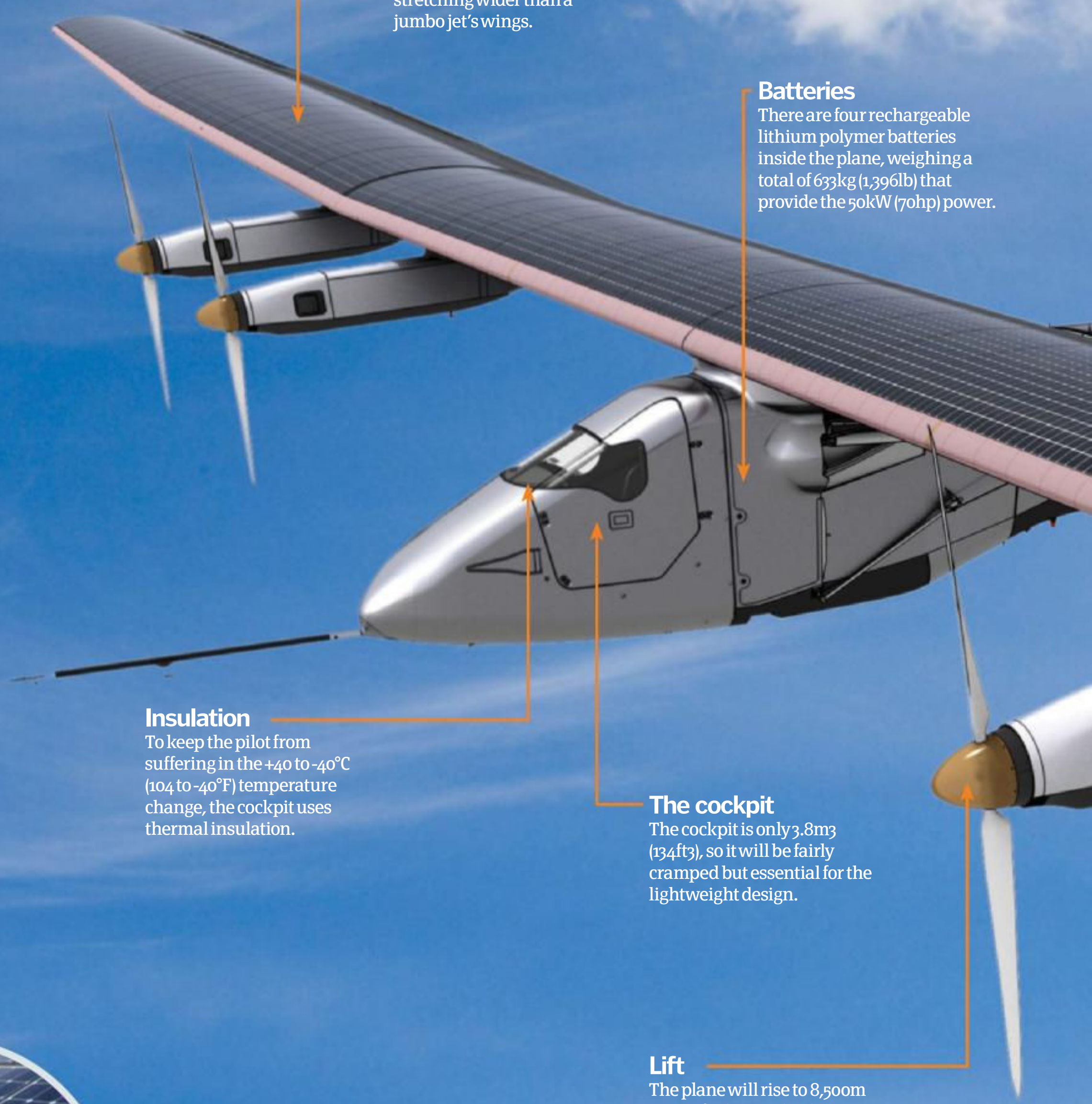
Another major player in the world of solar powered aviation is Solar Flight. Their newest project is Sunseeker Duo, which is the only two-seater solar-powered aeroplane in operation. It follows a similar pattern to the Solar Impulse 2, with long wings covered with solar panels and a lightweight body. Its panels have been improved to become 50 per cent more efficient than their predecessors. It can fly for 12 hours and its engine produces 25 kilowatts (33.5 horsepower) of power.

The main question with using solar power is 'what happens at night?' During the day, not all the energy is used. Enough will be stored in the batteries to allow the aircraft fly at night.

The Solar Impulse 2 landed successfully on the 3rd of July 2015, and marked a huge achievement for alternative energy. The next challenge for solar-powered aviation is to be able to carry multiple passengers, so hopefully one day tourists can use the Sun on their way to soaking it up.

Anatomy of a solar aircraft

How the Solar Impulse 2 gets off the ground and stays there



Wings
The wingspan of the plane is a total of 72m (236ft), stretching wider than a jumbo jet's wings.

Batteries
There are four rechargeable lithium polymer batteries inside the plane, weighing a total of 633kg (1,396lb) that provide the 50kW (70hp) power.

Insulation
To keep the pilot from suffering in the +40 to -40°C (104 to -40°F) temperature change, the cockpit uses thermal insulation.

The cockpit
The cockpit is only 3.8m3 (134ft3), so it will be fairly cramped but essential for the lightweight design.

Lift
The plane will rise to 8,500m (27,887ft) during the day to make the most of the power and then drop to 1,500m (4,921ft) at night.

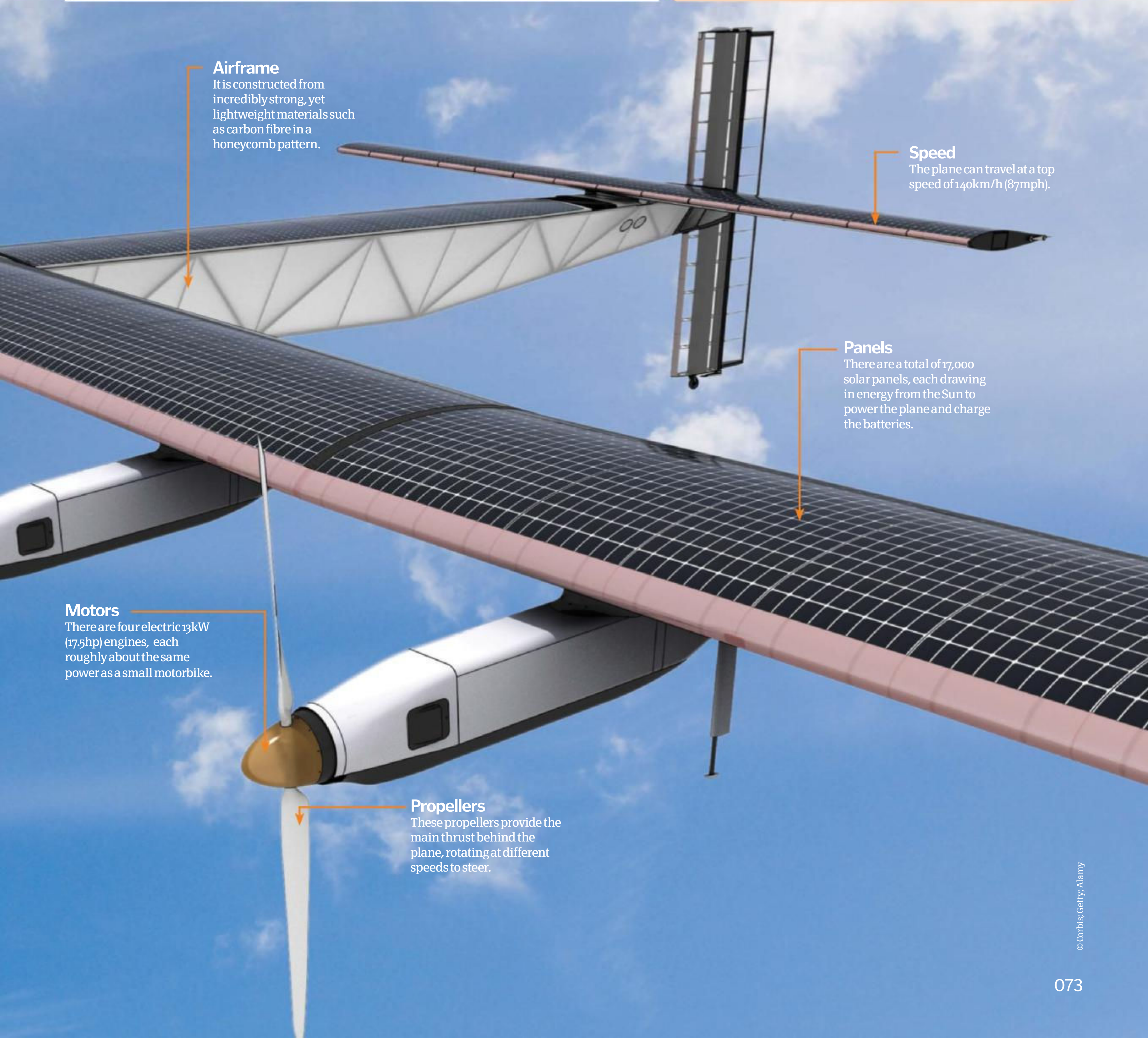
How solar panels work

How exactly do solar panels convert sunlight to energy? Inside a solar panel is a number of silicon cells, placed on top of each other. One of the silicon atoms has all its electrons, while the one beneath it has a few missing. In order to restore the balance, the full silicon atom transfers electrons to the one below, but it needs light to trigger the process. Once the sunlight hits the panel, electrons are transferred from one silicon cell to the other, thus creating an electric current that powers a load.

Despite the massive wingspan, the Solar Impulse weighs about the same as two small cars

Close up power

ESA's Solar Orbiter will be getting a ridiculous boost of solar energy when it takes off in 2017 as its mission is to get closer to the Sun than any probe has before, in order to take incredible pictures of the star. With its 3.1-metre x 2.4-metre (10.2-foot x 7.9-foot) sunshield, this craft will travel just 42 million kilometres (26 million miles) away from the Sun to take high-resolution images and perform experiments. It has been rigorously tested, as it will experience temperatures ranging from 520 degrees Celsius (968 degrees Fahrenheit) to -170 degrees Celsius (-274 degrees Fahrenheit). Its aim is to help scientists lean more about the inner heliosphere and how solar activity affects it, answering questions about solar winds, coronal magnetic fields and solar eruptions.



© Corbis; Getty; Alamy

On board Air Force One

Transporting the US president is no small task, requiring specialised aircraft that can respond to a variety of different threats and situations

Air Force One is the call sign used to designate aircraft specially fitted out to carry the president of the United States while on official business. Currently two planes carry the Air Force One name – both customised versions of the Boeing VC-25A jetliner that have been in service since 1990.

Appearing like a standard airliner on the outside, Air Force One is in fact an incredibly complex aircraft, decked out with a number of hi-tech facilities that make it suitable for carrying arguably the most powerful person on the planet. Over its 372 square metres (4,000 square feet) of floor space, these include a surgery-class medical bay, a communications suite that can act as a command centre for military operations, plus a fully equipped office with satellite phone and wireless internet connection. There are also a hotel-style presidential suite capable of housing the First Family with ease, a press cabin for resident photographers and journalists, a large conference room, as well as a series of other cabins for guests, flight staff and security.

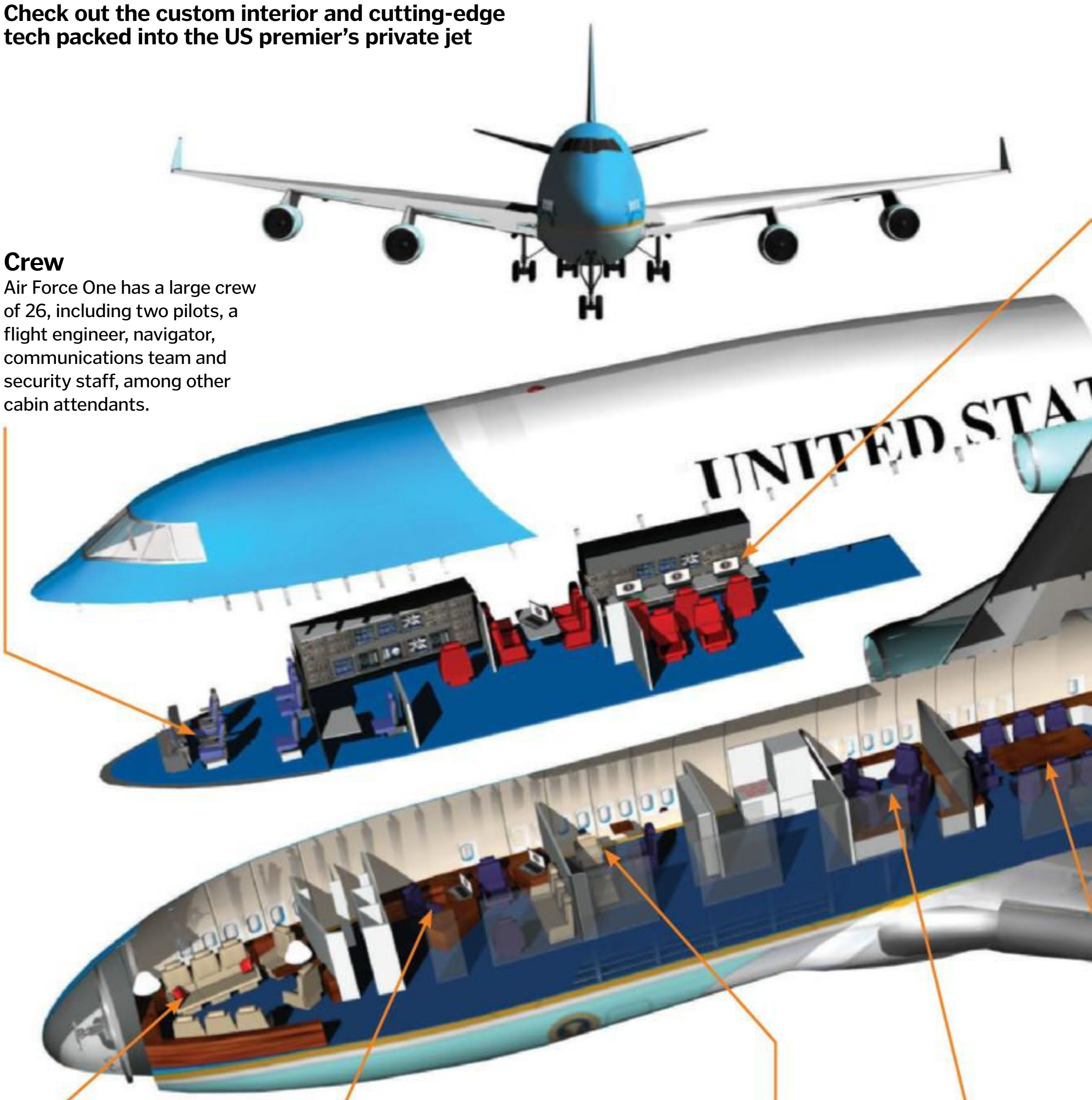
Air Force One is powered by four General Electric CF6-80C2B1F turbofan jet engines, which each deliver a substantial thrust of around 25,500 kilograms-force (56,200 pounds-force). Together, these grant Air Force One a maximum speed of 1,014 kilometres (630 miles) per hour, which, when combined with its cavernous fuel tanks, allow the president and retinue to travel anywhere within a 12,550-kilometre (7,800-mile) range fairly rapidly and without having to refuel.

If for any reason Air Force One needed to remain airborne past that distance – for example, in the event of nuclear war – then a fuel top-up can be handled during flight, as the VC-25A has a refuelling receptacle built in.

There are over 85 telephones and multi-frequency radios on board, with a staggering 383 kilometres (238 miles) of electrical wiring connecting all the various systems. Both the flight deck and communications centre, as well as every other electrical system on the aircraft, are electromagnetically shielded to prevent them from being taken out by electromagnetic pulses generated by a nuclear blast.

A plane fit for a president

Check out the custom interior and cutting-edge tech packed into the US premier's private jet



Crew
Air Force One has a large crew of 26, including two pilots, a flight engineer, navigator, communications team and security staff, among other cabin attendants.

Medical room
In the event of injury any passengers on Air Force One can be treated in a dedicated medical bay by an on-flight doctor. It can serve as a full surgery too.

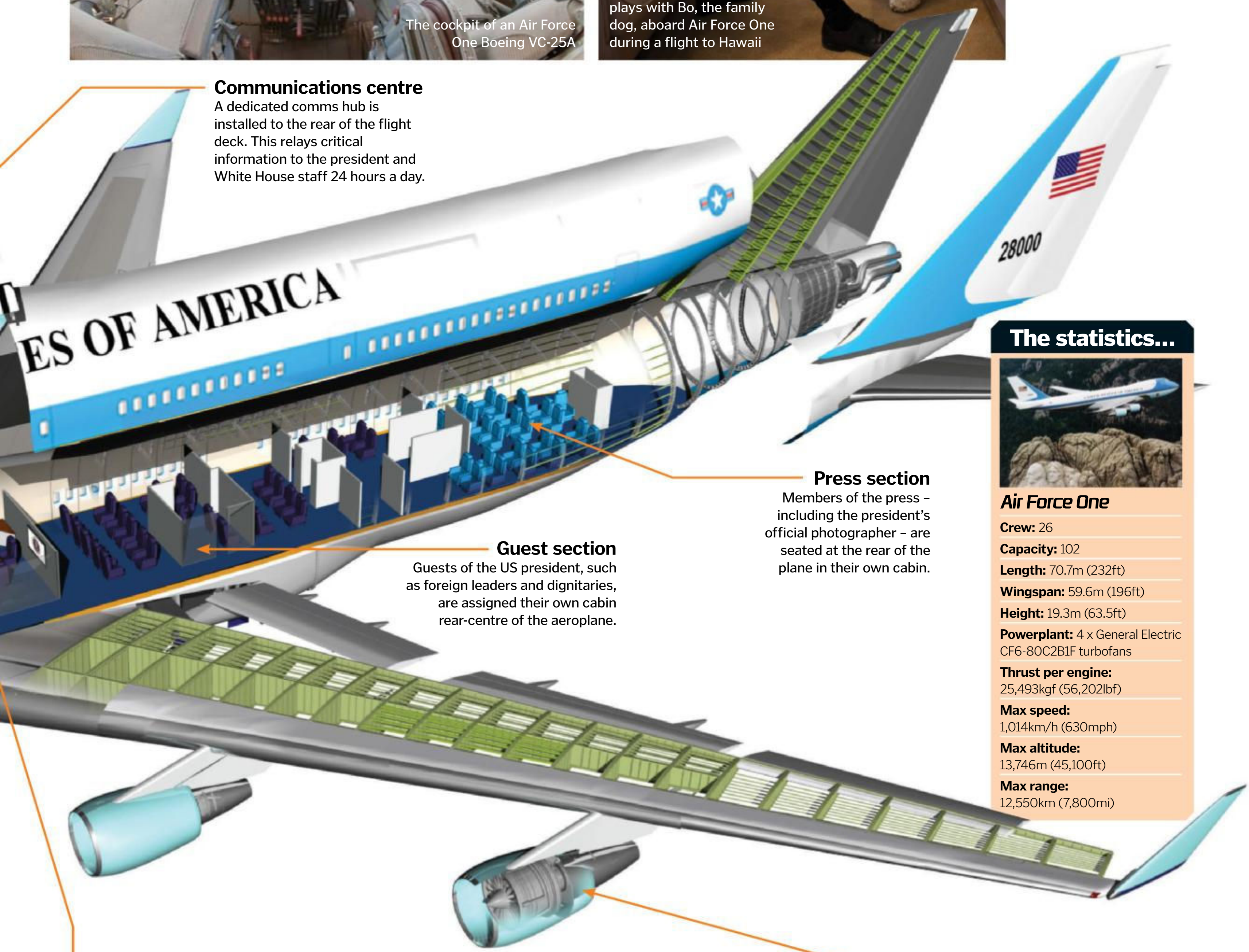
Presidential suite
This has all the amenities of a high-class hotel room, allowing the US premier and his family to relax or sleep during long-haul flights.

President's office
Despite travelling, more often than not the US president needs to work while flying. This is made possible by a fully kitted-out office area equipped with satellite phone.

Security
Members of the US Secret Service follow the president at all times, including on Air Force One. They are assigned their own cabin and security positions throughout the aircraft.

The cockpit of an Air Force One Boeing VC-25A

President Barack Obama plays with Bo, the family dog, aboard Air Force One during a flight to Hawaii



Communications centre

A dedicated comms hub is installed to the rear of the flight deck. This relays critical information to the president and White House staff 24 hours a day.

Press section

Members of the press – including the president's official photographer – are seated at the rear of the plane in their own cabin.

Guest section

Guests of the US president, such as foreign leaders and dignitaries, are assigned their own cabin rear-centre of the aeroplane.

Conference room

In the event of a major incident – such as a nuclear attack – the president along with his chiefs of staff can convene in Air Force One's conference room to discuss tactical options and any intel.

Powerplant

The VC-25A is powered by four General Electric CF6-80C2B1F turbofans, each capable of outputting 25,493kgf (56,202lbf) of thrust. These grant the aircraft a top speed of 1,014km/h (630mph).

The statistics…

Air Force One

Crew: 26

Capacity: 102

Length: 70.7m (232ft)

Wingspan: 59.6m (196ft)

Height: 19.3m (63.5ft)

Powerplant: 4 x General Electric CF6-80C2B1F turbofans

Thrust per engine: 25,493kgf (56,202lbf)

Max speed: 1,014km/h (630mph)

Max altitude: 13,746m (45,100ft)

Max range: 12,550km (7,800mi)

THE NEW CONCORDE

Concorde's successors are now on the horizon, offering Mach-shattering speeds, alongside hugely reduced noise and fuel consumption compared to their famous forebear

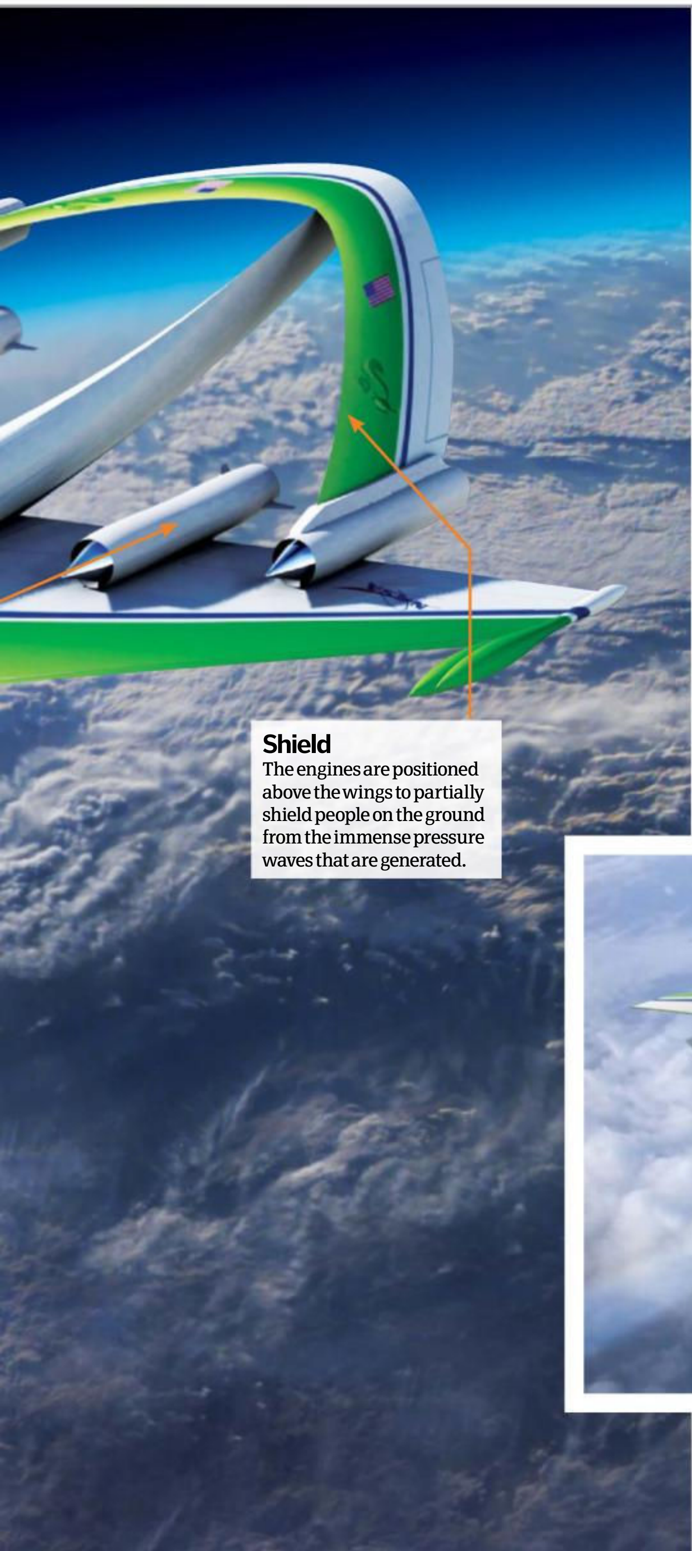
In 1976 we could fly commercially from London to New York in just three and a half hours. That's over 5,550 kilometres (3,460 miles) at an average speed of 27 kilometres (17 miles) per minute. For context, the same journey in a Mini Metro travelling continuously at 97 kilometres (60 miles) per hour would take close to 58 hours (almost two and a half days) – and that's not considering the fact a Mini can't fly!

Today, crossing the 'pond' – ie the Atlantic Ocean – takes more like seven and a half hours, a trip that definitely puts the 'long' into long-haul flight. So, this raises the question: what went wrong? A one-word answer is sufficient: Concorde. The Concorde supersonic jet, the piece of technology that allowed such outrageous flight times was retired for good back in 2003 after 27 years of service (for more information see the 'End of Concorde' boxout on p76). Further, no other supersonic jet has been introduced in its absence – leaving customers stuck travelling at subsonic speeds no matter where they wish to fly around the globe, and having to endure the longer flight times.

Things, however, are all about to change. Driven by the ever-growing notion of the global village – the interconnectedness of all nations – and fired by the gaping void left behind by Concorde, a new wave of supersonic jetliners have been put into production, aiming to pick up where Concorde touched down. The aim is to radically transform the speed, efficiency and impact of future commercial supersonic travel.

From Lockheed Martin's Green Machine concept (a supersonic jet capable of mitigating the effects of sonic boom) through Aerion Corporation's Supersonic Business Jet (a machine that introduces a radical new technology called natural laminar flow) and on to Boeing's Icon-II design (an aircraft that boasts far greater noise reduction and fuel efficiency) the future of this industry is already looking very exciting. For the first time, private companies are collaborating with the best research institutes in the world (one of which being NASA) to make supersonic flight a reality once more, outside of the military sphere that is.

Of course, while the roadmap to realisation is becoming more concrete with each passing day,



there are still major hurdles that need to be overcome – something driven by a call from NASA for companies to investigate ways to cancel out the damaging effects of sonic booms, increase fuel efficiency and improve the ability of supersonic jets to break through the transonic envelope (see the 'Shattering Mach 1' boxout over the page). These factors represent just a few of the challenges of not only achieving supersonic flight, but also making it commercially viable where Concorde ultimately wasn't.

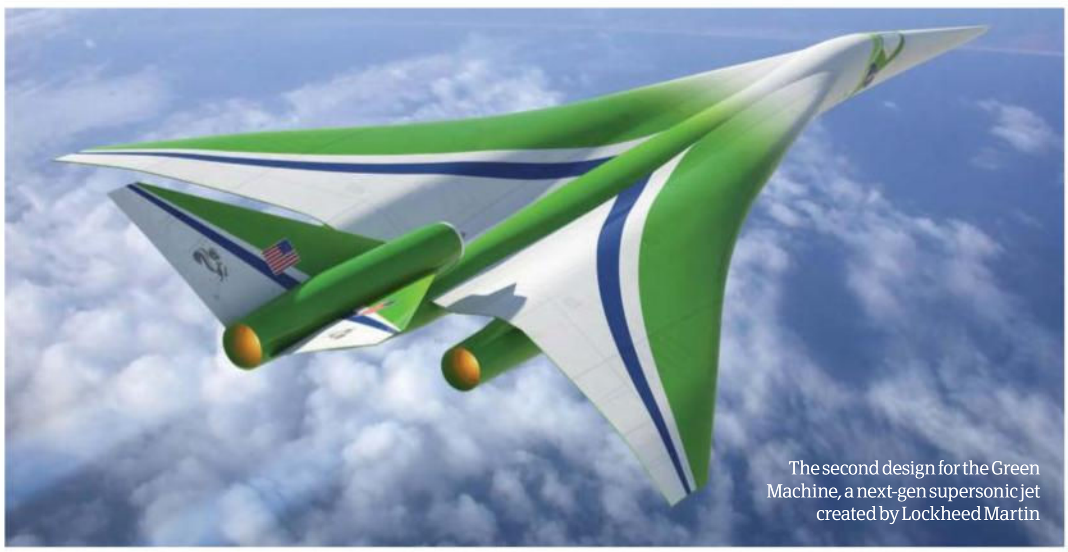
In this feature, we take a much closer look at the science of travelling at supersonic speeds as well as at some of the aircraft and advanced technology currently leading the charge against Earth's sound barrier.

The Supersonic Green Machine

Lockheed Martin's Green Machine passenger plane offers a glimpse into the future of high-speed, eco-minded air travel

Lockheed Martin's Supersonic Green Machine recently piqued interest at NASA thanks to its inverted-V engine array. The array, which sits above the wings, has been designed to mitigate the generation of sonic booms, the loud and distinctive cracking sound heard when an object passes through the sound barrier. The positioning of the engines is not just an aesthetic choice either, but a strategic one that harnesses the wing area to effectively shield portions of the ground against pressure waves, thereby reducing the audible noise and 'boom carpet' heard on the ground.

Interestingly, the design has also been developed to get as close as possible to the ideal aerodynamic form for a supersonic jet, with the fuselage closely resembling the Sears-Haack model (a cigar shape that minimises the creation of wave drag). While no concrete specifications have been released, according to Lockheed Martin and NASA, which have run model-sized trials in wind tunnels, the jet would offer speeds comparable to Concorde, but with significant reductions in fuel burn and noise output.



The second design for the Green Machine, a next-gen supersonic jet created by Lockheed Martin

Banishing the boom

For the latest supersonic jets to become a reality, special technology is being designed to keep the noise down

Even when active, Concorde was prohibited from flying at supersonic speeds over the USA due to the impact of sonic booms. Indeed, the inability of Concorde to fly over the majority of habituated land meant it had to follow elongated and inefficient flight routes, greatly damaging its efficiency.

Eradicating these sonic booms is therefore key to any future supersonic jet being greenlit for production, with nations worldwide concerned with the 'boom carpet' (the avenue on a jet's flight path where sonic booms can be heard). Three key developments in this area have been the recent introduction of far thinner wings than Concorde, the repositioning of the engines above the wings – this effectively turns the wings into shields, diverting pressure waves away from the ground – and the creation of pressure-sculpting air inlets for the aircraft's turbines.

While no physical jet has yet to enter production, experimentation by US space agency NASA in 2011 into sonic booms confirmed that, if the new designs could adequately hide the engine outlets within a narrow fuselage, then almost all audible noise could be cancelled out.

Aerion SBJ

The SBJ supersonic plane will be able to cruise at Mach 1.6, taking passengers from Paris to NYC in just over four hours

Aerion Corporation is arguably at the cutting edge of supersonic flight research, with the company collaborating closely with NASA on developing the tech necessary to introduce its Supersonic Business Jet (SBJ), a piece of kit that will be able to take passengers anywhere at over 1,900 kilometres (1,200 miles) per hour.

This ability will come courtesy of the advanced research into a technology called natural laminar flow (NLF). Laminar flow is the condition in which air in a thin region adjacent to a plane's wings stays in smoothly shearing layers, rather than becoming turbulent. This means that the more laminar the airflow, the less aerodynamic friction drag impinges on the wings, which improves both range and fuel economy.

This is possible due to the tapered bi-convex wing design, which is constructed from carbon epoxy and coated with a titanium leading edge. The partnering of this with the SBJ's aluminium composite fuselage delivers an aircraft that not only provides a range of over 7,400 kilometres (4,600 miles) and a maximum altitude of 15,544 metres (51,000 feet), but an aircraft that can do all this while sufficiently reducing fuel burn and therefore operating costs. The latter point is incredibly important as it was a primary factor that led to Concorde being scrapped.

The SBJ will be able to travel from New York to Paris in four hours and 15 minutes, almost half the time of a regular jetliner


The SBJ's cabin measures 9.1m (30ft) and allows for three dedicated seating areas

The statistics...

Aerion SBJ

Length: 45.2m (148.3ft)
Width: 19.5m (64.2ft)
Height: 7.1m (23.3ft)
Weight: 20,457kg (45,100lb)
Wing area: 111.5m² (1,200ft²)
Engines: 2 x PW JT8D-200
Max speed: Mach 1.6 (1,960km/h; 1,218mph)
Max range: 7,407km (4,603mi)
Max altitude: 15,544m (51,000ft)

The end of Concorde

Concorde was an engineering masterstroke. So why did the luxurious jetliner get shut down?

What was arguably the death knell for Concorde was the disastrous crash of Air France's Flight 4590 in 2000, which killed all 100 of its passengers, nine crew members and four people on the ground. The crash was caused by a titanium strip falling off a Continental Airlines DC-10 aircraft that had taken off minutes before the ill-fated Concorde. The strip pierced one of Flight 4590's tyres, caused it to explode and consequently sent rubber into one of the aircraft's fuel tanks. The resultant shockwave caused a major fuel leak, which then ignited due to electrical landing gear wires sparking.

Post-crash, despite Concorde being arguably one of the safest operational passenger airliners in the world, both Air France and British Airways – its only two operators – reported a steep decline in passenger numbers, leading both fleets to be decommissioned in 2003.


A British Airways Concorde taking off shortly before the jetliner's retirement

© James Gordon

Shattering Mach 1

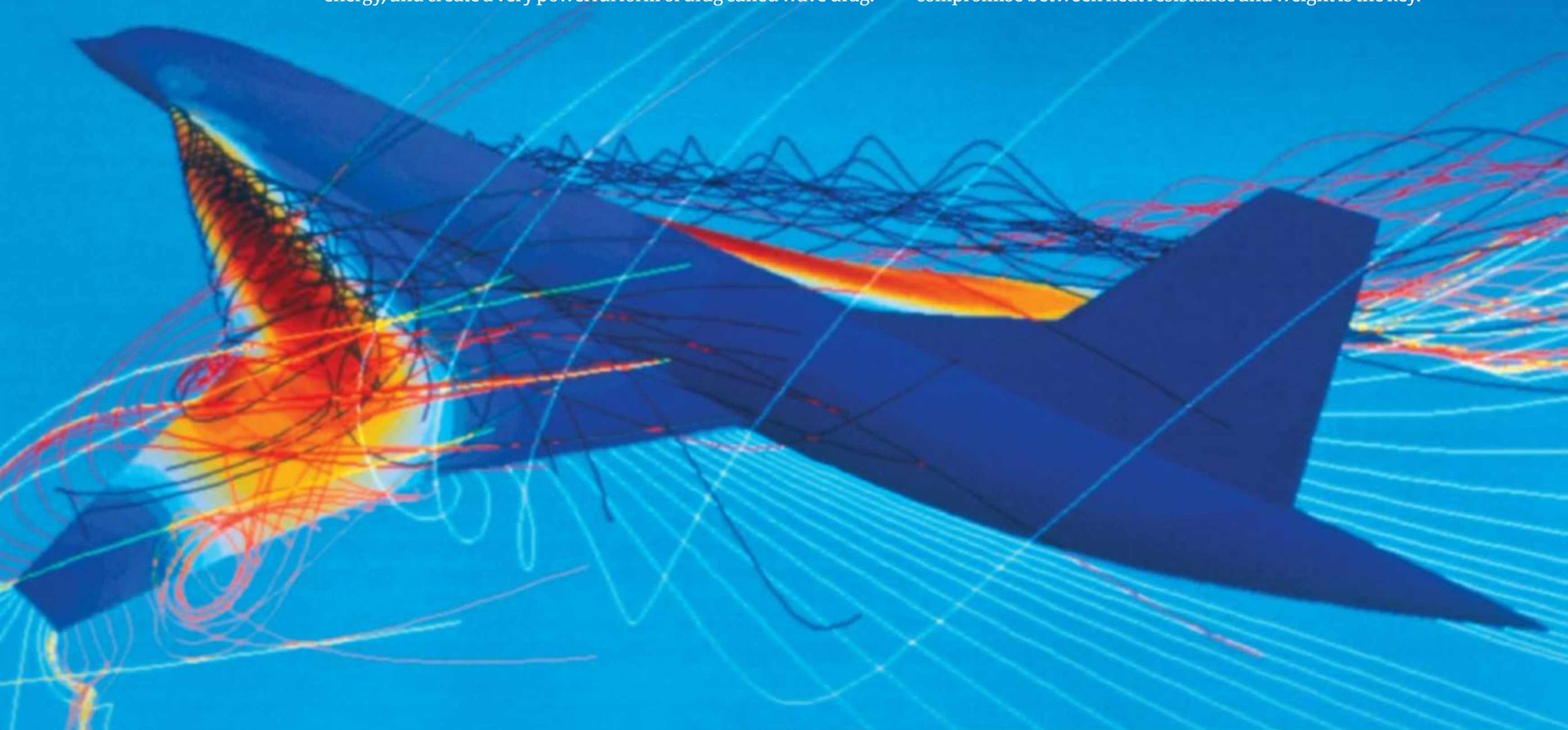
There is far more to creating a supersonic aircraft than simply strapping larger engines to a subsonic fuselage…

Supersonic aerodynamics are much more complex than subsonic aerodynamics for a variety of reasons, the foremost being breaking through the transonic envelope (around Mach 0.85-1.2). This is because to pass through this speed range supersonic jets require several times greater thrust to counteract the extreme drag, a factor that raises two key issues: shockwaves and heat.

Shockwaves come from the passage of air (with positive, negative or normal pressures) around the fuselage, with each part of the aircraft affecting its progress. As such, while air is bent around the thin fuselage with minimal effect, as it reaches the wings – a huge change in the cross-sectional area of the jet – it causes shockwaves along the plane's body. The resulting waves formed at these points bleed away a considerable amount of energy, and create a very powerful form of drag called wave drag.

To mitigate this, any supersonic jet design must allow for a smooth-as-possible change in cross-sectional areas, with the wings fluidly curving out from the fuselage.

Heat is the other big concern. Sustained supersonic flight – as a by-product of the drag it generates – causes all of its materials to experience rapid and prolonged heat, with individual parts sometimes reaching in excess of 300 degrees Celsius (572 degrees Fahrenheit). As such, conventional subsonic materials like duraluminium (or dural) are infeasible for a supersonic jet, as they experience plastic deformation at high temperatures. To counter this, harder, heat-resistant materials such as titanium and stainless steel are called for. However, in many cases these can push up the overall weight of the aircraft, so reaching a workable compromise between heat resistance and weight is the key.

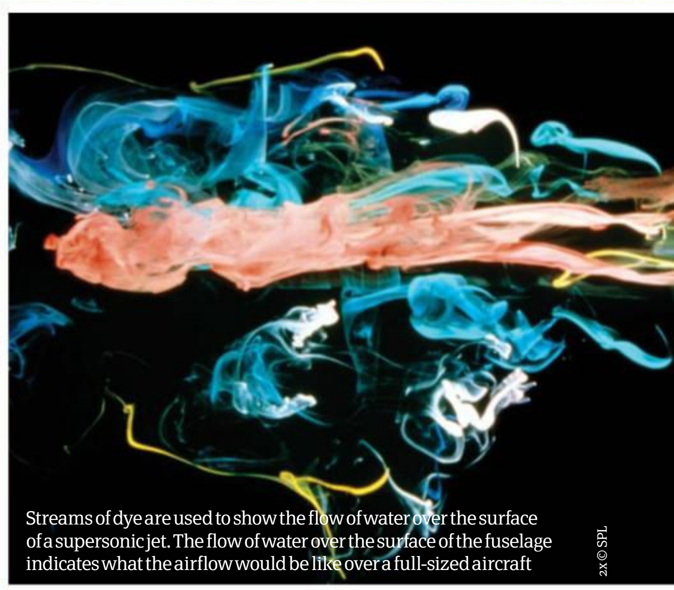


This shows the airflow over a supersonic jet's surface (including turbulence over the wing). The colour of the lines shows the air speed from red (fastest) to blue (slowest). In addition, the fuselage colour indicates its temperature, from blue (coolest) to red (hottest). Supersonic jet fuselages can be heated to over 100°C (212°F) by air friction

Sonic boom science

What are sonic booms and how are they generated?

Sonic booms are caused as, when an object passes through the air, it generates a series of pressure waves. These pressure waves travel at the speed of sound and increase in compaction the closer the object is to Mach 1 – approximately 1,225 kilometres (761 miles) per hour. When an object is travelling at the speed of sound (ie Mach 1), however, the sound waves become so compressed that they form a single shockwave, which for aircraft, is then shaped into a Mach cone. The Mach cone has a region of high pressure at its tip – before the nose of the aircraft – and a negative pressure at its tail, with air pressure behind the cone normal. As the aeroplane passes through these varying areas of pressure, the sudden changes create two distinctive 'booms': one for the high-to-low pressure shift and another for the low-to-normal transition.



Streams of dye are used to show the flow of water over the surface of a supersonic jet. The flow of water over the surface of the fuselage indicates what the airflow would be like over a full-sized aircraft

2x © SPL

On board a cargo plane

How do freight aircraft differ from passenger planes, enabling them to transport much greater loads all over the planet?

Cargo planes – whether used in the private, military or commercial sphere – are fixed-wing vehicles that have usually been designed with haulage in mind or have been converted from standard aircraft. Passenger planes commonly have a specialised hold that can store around 150 cubic metres (over 5,000 cubic feet) of freight, found on the underside of the craft. Dedicated freight planes don't need the seats or any of the other amenities on commercial flights – that said, their design amounts to much more than a hollowed-out passenger plane.

To make the most efficient use of the space available, the floor is lined with a walkway and electronic rollers that allow prepackaged pallets to be rolled back as far as possible, without the need for a forklift. Large cargo bay doors are installed to fit bigger items through and, in some examples, like the Boeing 747-400, the nose lifts up to allow particularly large items to pass down the body of the plane. With the demands of air freight ever increasing, aircraft with huge cargo capacities like the Airbus A300-600 Super Transporter (also known as the Beluga), are becoming the norm.

It's not enough just to increase the size of the aircraft hold though. In order for a cargo plane to efficiently and safely transport its mighty load, a number of adaptations must be made to the overall avian design. For example, the wings and tail are built high to allow the freight to sit near the ground and to facilitate loading; the fuselage is much bigger; and – similar to heavy goods vehicles – cargo planes typically feature a larger number of wheels to support their weight on landing.

Plane politics

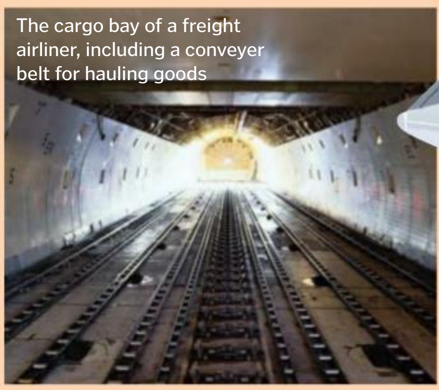
The Xian Y-20 is a military long-range transport plane that's still in development by China, although it has recently been filmed on a short test flight. It's a similar class of aircraft as Russia's Ilyushin Il-76 or the US Boeing C-17, and though China maintains a tighter guard over its military secrets than most, it has an estimated payload in the region of 72,000 kilograms (160,000 pounds) – that's quite a bit, by any country's standards! The PLAFF (People's Liberation Army Air Force), or avian branch of the Chinese military, had long favoured the development of fighter jets over this kind of support aircraft, so that the Y-20 project was sidelined when it started in 2005. However, following the Sichuan earthquake of 2008, China was unable to effectively drop relief supplies with its small fleet of cargo planes, so the US had to assist with two C-17s. This embarrassment undoubtedly spurred the Chinese government into pushing on with the Y-20's development.

Cargo plane credentials

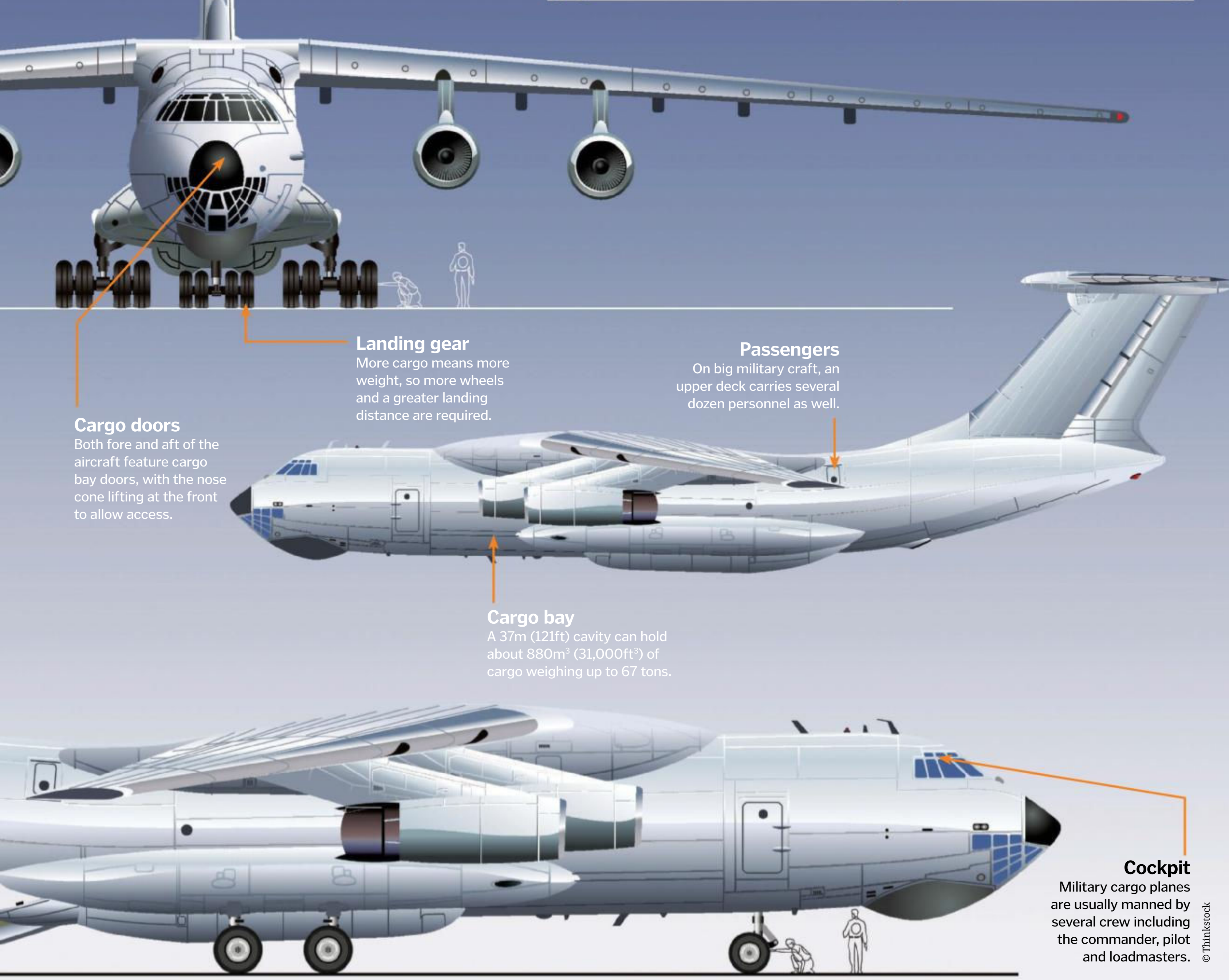
HIW pinpoints what a military cargo transporter needs to get the job done

Lightening the load

Depending on the type of cargo being carried (very large items or military vehicles may be exceptions), many cargo planes will use ULDs, or unit load devices. These allow the crew to prepackage cargo into single units that can more easily be loaded into the hold prior to the flight, saving a great deal of time. It's a similar system to that used in shipping, maximising the space used at the same time and, thus, increasing efficiency (and profits). The ULDs themselves are either robust and lightweight aluminium pallets or aluminium-floored containers with toughened plastic walls. The containers are sometimes converted into self-contained refrigeration units to store perishable goods.


The cargo bay of a freight airliner, including a conveyer belt for hauling goods


Lockheed Martin's C-5 Galaxy has 12 internal wing tanks with a total capacity of 194,370l of fuel



1. Wings
Through the Harrier's compact wings run a series of exhaust tubes that allow high-pressure air to be filtered from the engine to its tips, increasing stability during manoeuvres.

2. Nozzles
One of the Harrier's Pegasus engine vectoring nozzles. Through these four nozzles – which can be rotated through a 98.5-degree arc – the engine's thrust can be directed for vertical or short take-off.

VTOL aircraft

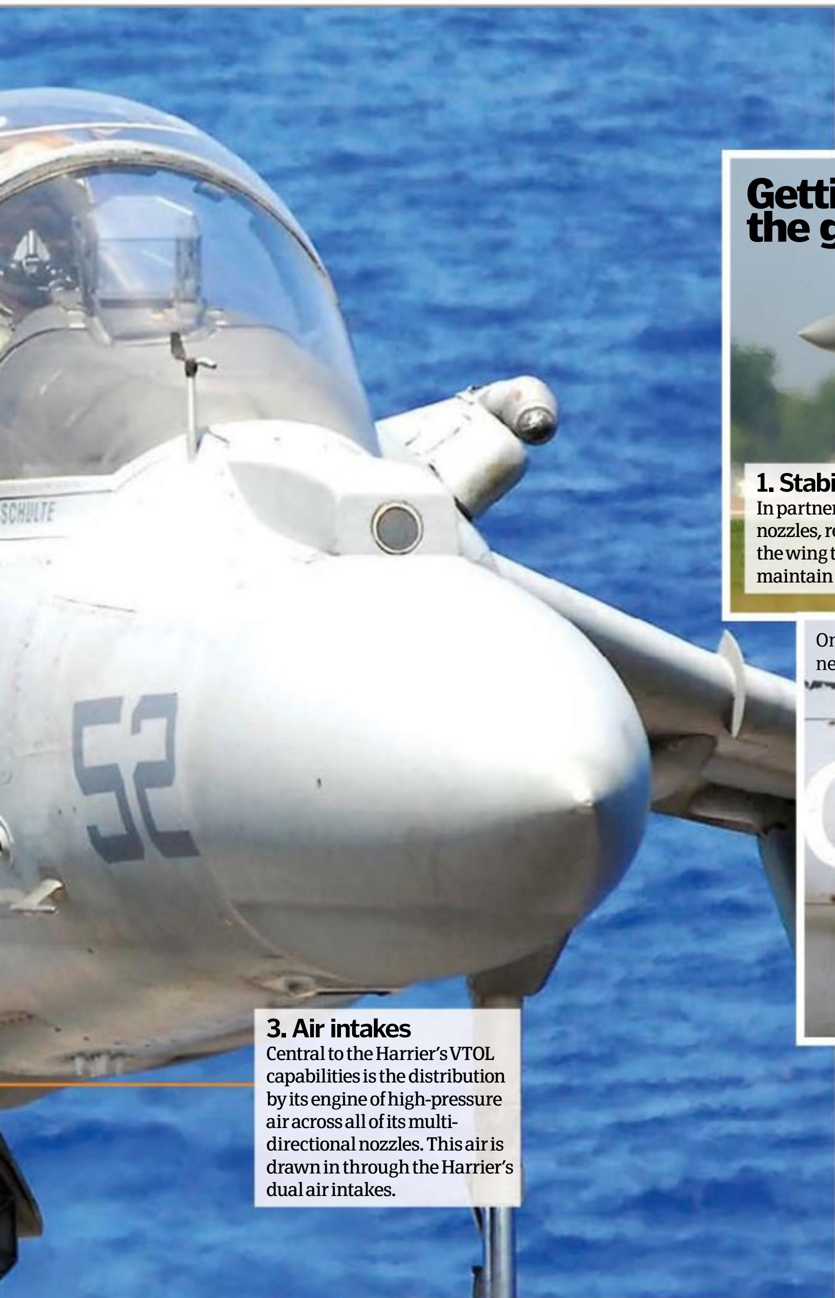
For the past 60 years, Vertical Take-Off and Landing (VTOL) aircraft have evolved massively as engineers have strived for what can be argued to be the Holy Grail of aeronautics

Harrier Jump Jet

The most famous of all VTOL aircraft, the Harrier fighter jet is utilised all over the world thanks to its advanced technology and aerodynamic versatility

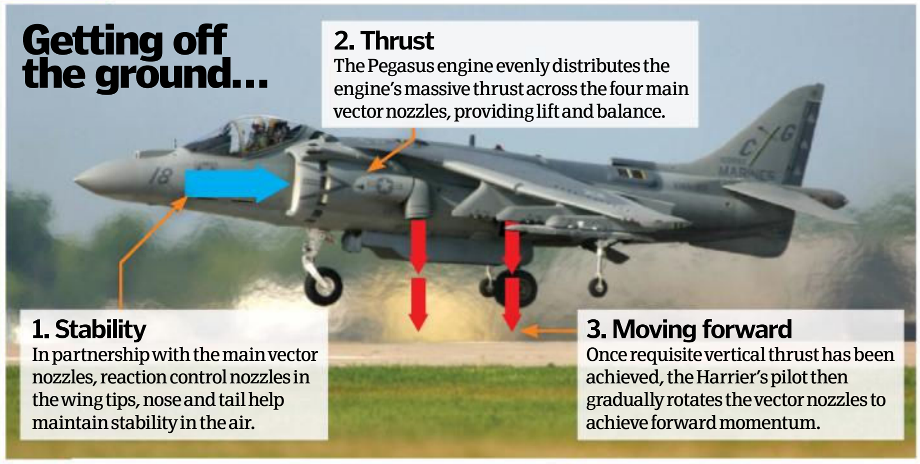
For the past 40 years, since its introduction in 1969, the Harrier Jump Jet has epitomised the vertical take-off and landing concept. Born amid a fervent arms race to produce a light attack, multi-role fighter with VTOL capabilities, the Harrier proved that VTOL could work in reality, advancing the vastly expensive and solely academic efforts that had been designed previously. Indeed, to this day it is still in operation world wide, and praised for its versatility and reliability.

The Harrier's VTOL capabilities are made possible by its Rolls-Royce Pegasus engine, a low bypass-ratio turbofan that features four rotating nozzles through which its fan and core airflows exhaust. These nozzles can be rotated by the pilot through a 98.5-degree arc, from the conventional aft (horizontal) positioning as standard on aircraft, to straight down,



3. Air intakes
Central to the Harrier's VTOL capabilities is the distribution by its engine of high-pressure air across all of its multi-directional nozzles. This air is drawn in through the Harrier's dual air intakes.

Getting off the ground...



1. Stability
In partnership with the main vector nozzles, reaction control nozzles in the wing tips, nose and tail help maintain stability in the air.

2. Thrust
The Pegasus engine evenly distributes the engine's massive thrust across the four main vector nozzles, providing lift and balance.

3. Moving forward
Once requisite vertical thrust has been achieved, the Harrier's pilot then gradually rotates the vector nozzles to achieve forward momentum.

One of the rotatable vector nozzles necessary to lift the Harrier vertically

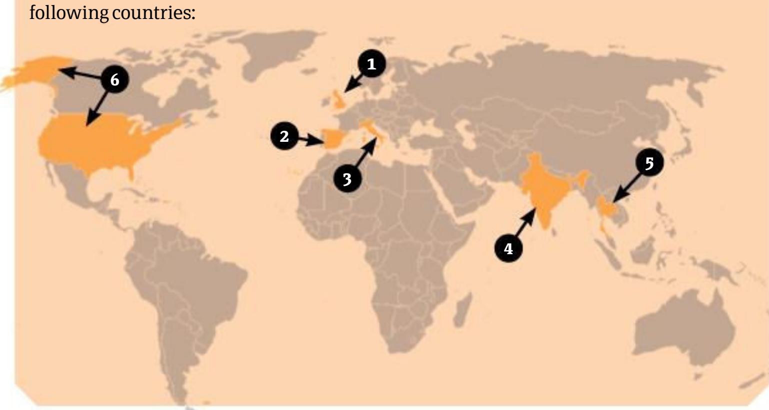
© Wyrdlight

A shot of the Rolls-Royce Pegasus engine that powers the Harrier

ON THE MAP

Harrier deployment
The Harrier is operated worldwide by many military organisations in the following countries:

1 UK
2 Spain
3 Italy
4 India
5 Thailand
6 USA



allowing it to take-off and land vertically as well as hover, to forward, allowing the Harrier to drift backwards. All nozzles are moved by a series of shafts and chain drives, which ensures that they operate in unison and the angle and thrust are determined in-cockpit by the pilot.

The control nozzle angle is determined by an additional lever positioned alongside the conventional throttle and includes fixed settings for vertical take-off (this setting ensures that true vertical positioning is maintained in relation to aircraft altitude), short-take off (useful on aircraft carriers) and various others, each tailored to aid the pilot's control of the Harrier in challenging flight conditions.

Of course, the nozzle lever can be incrementally altered too by the pilot, as in order to be able to fly the Harrier, fine control of the throttle in relation to the nozzle lever is central, adding an extra dimension to any potential pilot's training.

As well as the vectoring engine nozzles, the Harrier also requires additional reaction control nozzles in its nose (downward firing), wingtips (downward and upward firing) and tail (down and lateral firing) in order to remain stable once airborne. These nozzles are supplied with high-pressure air filtered from the engine and distributed through a system of pipes that run through the aircraft. Controlled through valves, this sourcing and utilisation of compressed air allows the pilot to adjust the Harrier's movement in pitch, roll or yaw.

This system is energised once the main engine nozzles are partially vectored and the amount of compressed air filtered to the anterior nozzles is determined by airspeed and altitude.

Vertol VZ-2

One of the first fully functional VTOL aircraft, the Boeing Vertol VZ-2 paved the way for the gargantuan V-22 Osprey

Many VTOL aircraft have been designed in the past 50 years, however most fall into one of two categories; those based on vectoring engine nozzles, and those that adopt tilt-wing technology. The Vertol VZ-2 falls into the latter category and was a wildly experimental research aircraft built in 1957 to investigate the tiltwing approach to VTOL. Resembling a conventional helicopter, albeit with an extended plane-like T-tail, the VZ-2 had an uncovered tubular framework fuselage and a single-seater bubble canopy.

The VZ-2 sported twin rotors powered from a single 700hp turboshaft engine, which positioned on its rotatable wings, in partnership with a series of small ducted fans in the T-tail, provided thrust and lift. Due to its lightweight design, the maximum speed achieved was 210mph and it had a low operational service ceiling of 13,800ft as well as a minuscule range of 210km.

Despite these shortcomings, the Vertol proved a very successful and fruitful experiment as over its eight-year life span it made 450 flights, including 34 with full vertical to horizontal transitions. The heritage of the VZ-2 can be seen today in the titanic tilt-rotor design and technology used on the V-22 Osprey.

© George Chirnilevsky

The first non-transition test flight of the VZ-2

"The VZ-2 sported twin rotors powered from a single 700hp turboshaft engine"

The statistics…

Vertol VZ-2

Crew: 1
Length: 8.05m
Wingspan: 7.59m
Height: 4.57m
Weight: 3,700lb
Engine: 1x Avco Lycoming YT53-L Turboshaft

Bell X-14

An experimental fixed-wing aircraft, the X-14 pushed back the boundaries of VTOL technology

Unlike the Vertol VZ-2, Bell's X-14 experimental VTOL aircraft was crafted and designed to be as close to existing aeroplanes as possible, with it even being constructed from parts of other existing aircraft. Not only were its wings fixed but its engine was in the standard horizontal position and, with a top speed of 180 miles per hour and operational service ceiling of 20,000 feet, the X-14's design appeared conventional. However, the X-14 was one of the first VTOL aircraft to utilise the emerging concept of multi-directional engine thrust, relying on a system of movable vanes to control the direction of its engine's power.

Interestingly, after a couple of years of successful flights, the aircraft was delivered to the NASA Ames Research Center as – in addition to providing a great deal of data on VTOL flight – its control system was similar to the one proposed for the lunar module and it was deemed a worthy test vehicle for space training. Indeed, Neil Armstrong, the first man to walk on the moon, flew the X-14 as a lunar-landing trainer and it was continually used by NASA until 1981 (seeing a total of 25 pilots climb in and out of its cockpit) when it was retired from service.

The statistics…

Bell X-14

Crew: 1
Length: 7.62m
Wingspan: 10.36m
Height: 2.40m
Weight: 3,100lb
Engine: 2x Armstrong Siddeley Viper 8 Turbojet

The X-14 being prepped on runway before a test flight

The Bell X-14 on a demonstration flight

A Yak-38 on the deck of a Soviet aircraft carrier

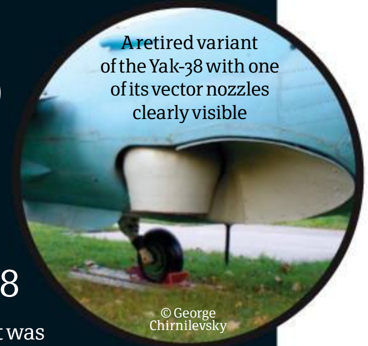
The statistics...

Yak-38

Crew: 1	
Length: 16.37m	
Wingspan: 7.32m	
Height: 4.25m	
Weight: 16,281lb	
Engine: 1x Tumansky R-28 V-300 Turbojet	

Yak-38

The Soviet Naval Aviation's first and only foray into VTOL multi-role combat aircraft, the Yakovlev Yak-38



A retired variant of the Yak-38 with one of its vector nozzles clearly visible

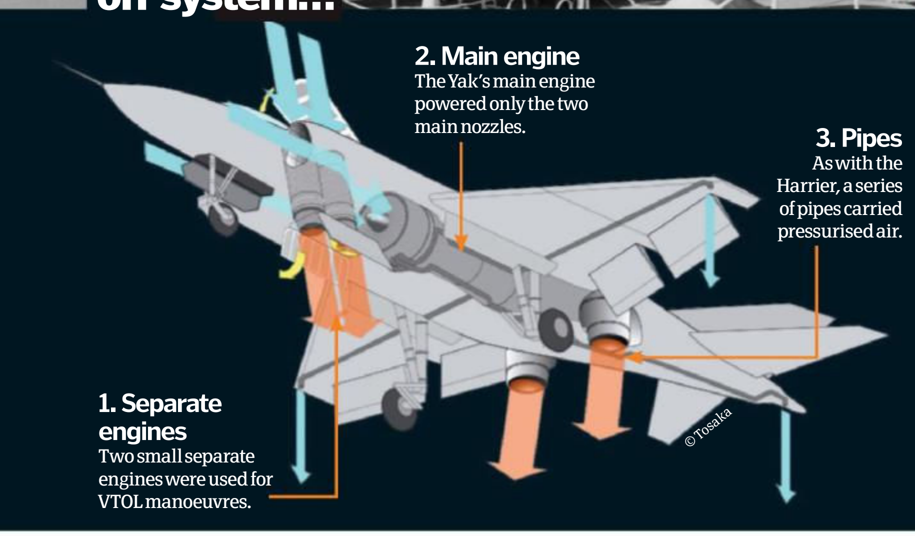
© George Chirnilevsky

Influenced in design by the British Hawker P.1154 and Harrier Jump Jet, the Yak-38 VTOL aircraft looked similar to its contemporaries, but its radically different internal configuration and general poor quality build and systems turned out to be a costly mistake. Contrary to the Harrier's single Pegasus engine, where thrust was vectored through four nozzles from a single source, the Yak-38 featured only two nozzles from the main engine, relying on a pair of separate, less-powerful engines housed in the front portion of the aircraft to be used in conjunction for vertical take-off and landing.

Apart from being a less-refined and underdeveloped system, the Yak-38 was built en-masse; however, soon it encountered massive problems during sea trials. In hot weather the separate lift jets often failed to start (due to oxygen starvation), leaving it stranded on the flight deck and while it was initially deemed capable of carrying heavy payloads, the hot weather also reduced its operational range to such an extent that only extra fuel tanks could be carried. Further, the average engine life span of the aircraft was a minuscule 22 hours and many pilots encountered serious engine problems in every flight they undertook (over 20 Yak-38s crashed due to system/engine failure), with it quickly gaining a reputation as a killer. Finally, it was horrendously difficult to fly and could only be landed by remote telemetry/telecommand link, rendering it useless in land warfare.

Obviously, the Yak-38 did not live up to its conceptual ideal – a multi-mission 980km/h combat jet with VTOL capabilities, a service ceiling of 40,000ft and an operational range of 240km – and after a final deadly crash in June 1991 was retired out of service.

Yak-38 take-off system...



1. Separate engines
Two small separate engines were used for VTOL manoeuvres.

2. Main engine
The Yak's main engine powered only the two main nozzles.

3. Pipes
As with the Harrier, a series of pipes carried pressurised air.

V-22 Osprey

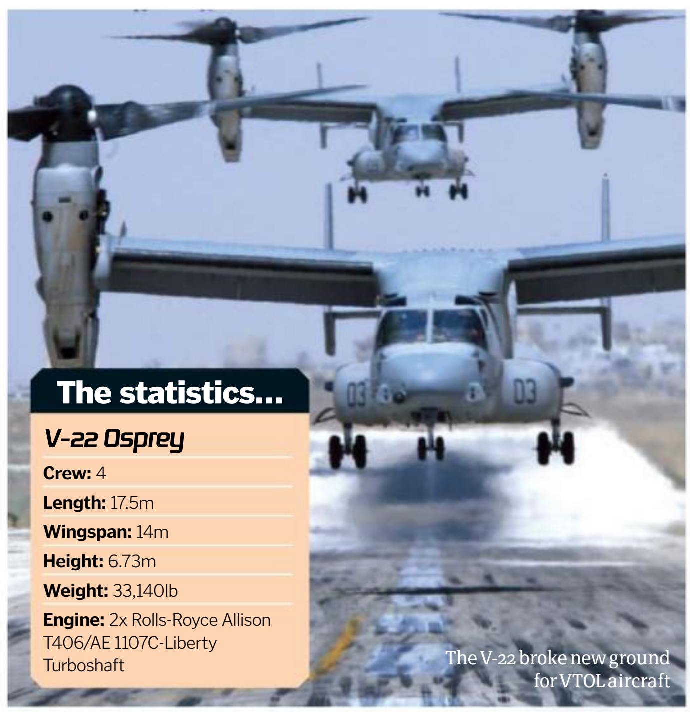
The world's first tilt-rotor aircraft, the V-22 Osprey is at the cutting edge of VTOL technology

The pinnacle of tilt-rotor/wing VTOL aircraft, the V-22 has been in development for 30 years and offers the cargo carrying capabilities of a heavy lift helicopter, with the flight speed, altitude, endurance and range of a fixed-wing cargo plane.

This fantastic hybrid of two distinct forms of aircraft comes courtesy of its revolutionary tilt-rotor technology – twin-vectoring rotors that can be adjusted over 90 degrees by the pilot – which attached to foldable fixed-wings, allow for vertical take-off and then conventional flight. Both rotors are powered by Allison T406-AD400 tilt-rotor engines that – considering its massive size and carrying capacity (20,000 pounds internally) – develop 6,150hp each.

Interestingly, the V-22's design, despite being more accomplished at short take-off and landing (STOL) manoeuvres, loses out to tilt-wing VTOL aircraft – such as demonstrated in the Vertol VZ-2 – in VTOL manoeuvres by ten per cent in terms of vertical lift. However, due to the lengthy periods of time that the V-22 can maintain its rotors over 45 degrees, longevity of the aircraft is greatly improved.

Unfortunately, despite current safe and successful operation in the Iraq and Afghanistan conflicts, during testing numerous accidents occurred involving the V-22, resulting in over 30 deaths to crewmen and combat troops.



The statistics...

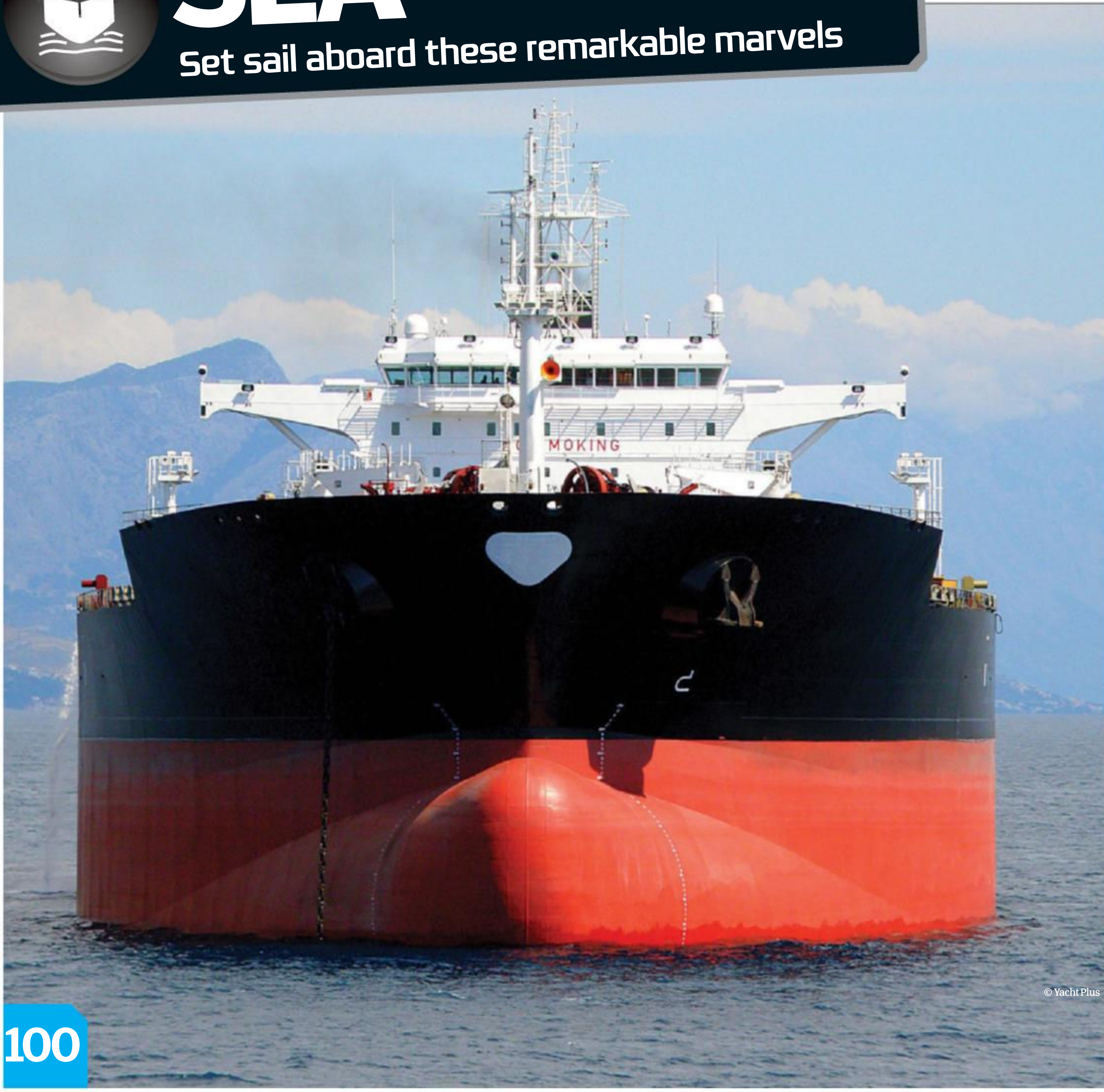
V-22 Osprey

Crew: 4	
Length: 17.5m	
Wingspan: 14m	
Height: 6.73m	
Weight: 33,140lb	
Engine: 2x Rolls-Royce Allison T406/AE 1107C-Liberty Turboshaft	

The V-22 broke new ground for VTOL aircraft

SEA

Set sail aboard these remarkable marvels



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© Yacht Plus

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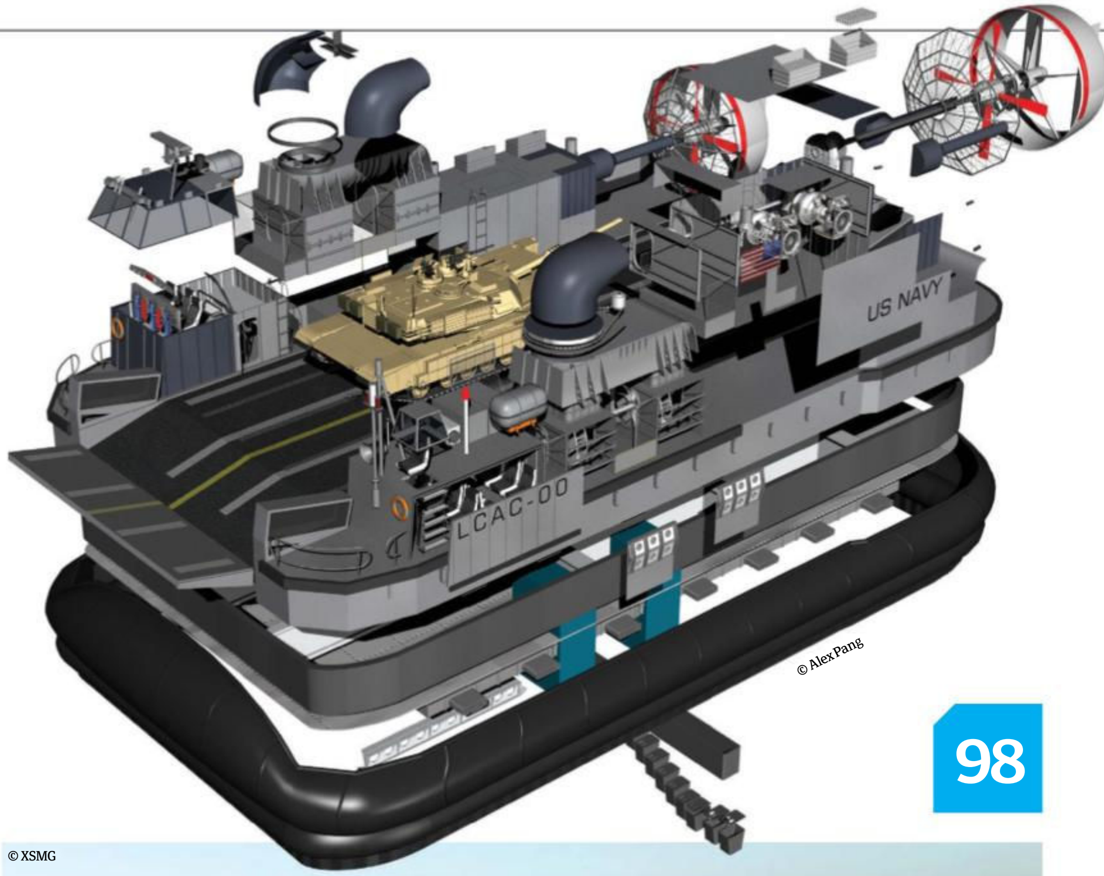

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Ocean hunters

These amazing feats of engineering bring the ocean depths closer than ever before

What lies beneath? This question has fascinated mankind for decades. We know more about the surface of the Moon than we do about our planet's deep oceans, as the limitations of planning a visit to the bottom of the sea are as many as venturing into space. But when nature throws problems at us, we hit back with technological solutions.

It's thought an English innkeeper, musing over the properties of buoyancy and water displacement, dreamt up the first submarine in 1580. From there, the principal of taking humans from sea level down to the deepest-known parts of the ocean in a pressurised cabin has grown into a colossal industry, important to scientists, the military and explorers alike.

But what are the benefits of diving so deep and what is there to see? Studying the seabed and its geological and topographical properties at certain regions can help us learn more about the surface of our planet. Scientists studying plate tectonics can learn plenty from ocean trenches, gaining knowledge that may lead to some great advancements in earthquake predictions and tsunami warning systems.

Similarly, the study of the decaying matter that collects on the ocean floor may help us to understand more about how carbon cycles through our ecosystems and how it is stored in the oceans. In turn this may have implications for our understanding of climate change.

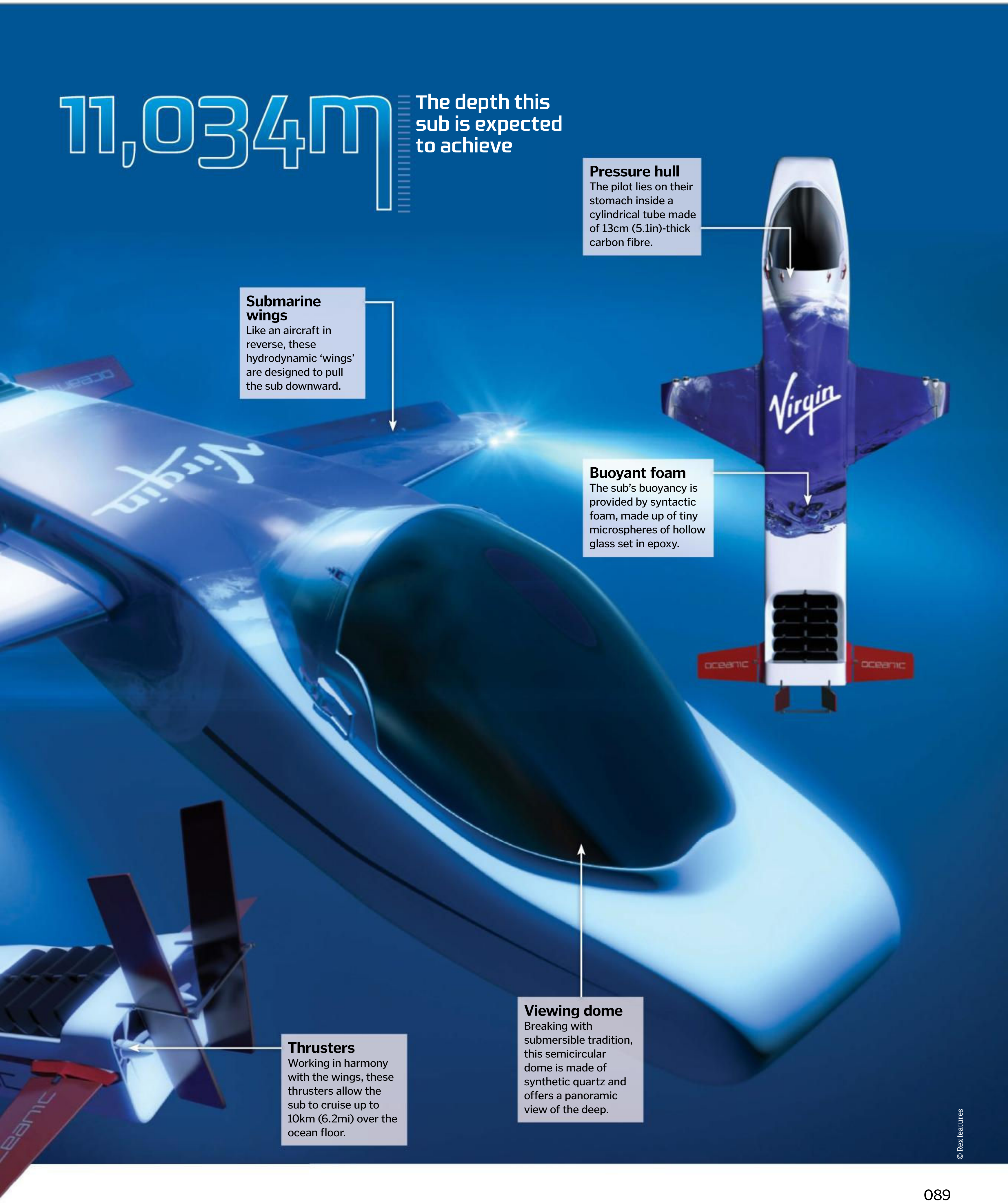
Submersibles are manned submarines, usually carrying around three crew members. One of the most famous and longest-serving submersibles out there is Alvin, the first of its kind capable of carrying passengers, owned by the Woods Hole Oceanographic Institution in Massachusetts, USA. Also available for deep-ocean exploration and study are ROVs, or Remotely Operated Vehicles. These are robots that can be controlled from their parent ship, equipped with cameras and tools to take images and samples from the deep.

At the bottom of the ocean, hydrostatic pressure is a major adversary. For every ten metres (33 feet) in depth, the pressure increases by one bar (14.5 pounds per square inch). At full-ocean-depth, that

Emerging technology is behind many of Virgin Oceanic's new deep-sea exploration vessel

Virgin Oceanic submersible

Explore Richard Branson's innovative craft for deep-ocean adventure, designed by sub builder Graham Hawkes



11,034m The depth this sub is expected to achieve

Pressure hull
The pilot lies on their stomach inside a cylindrical tube made of 13cm (5.1in)-thick carbon fibre.

Submarine wings
Like an aircraft in reverse, these hydrodynamic 'wings' are designed to pull the sub downward.

Buoyant foam
The sub's buoyancy is provided by syntactic foam, made up of tiny microspheres of hollow glass set in epoxy.

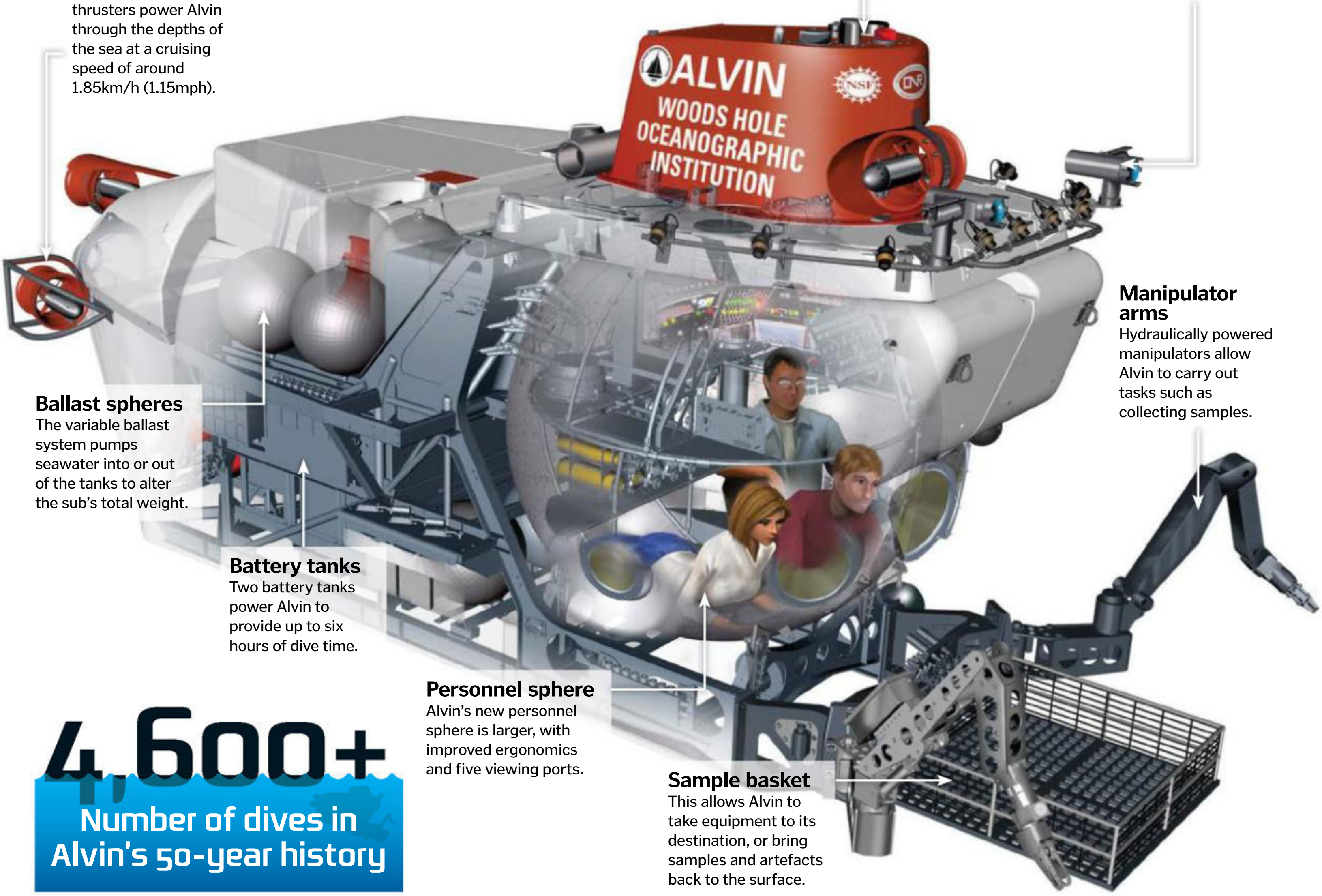
Viewing dome
Breaking with submersible tradition, this semicircular dome is made of synthetic quartz and offers a panoramic view of the deep.

Thrusters
Working in harmony with the wings, these thrusters allow the sub to cruise up to 10km (6.2mi) over the ocean floor.

© Rex features

Inside Alvin

Take a tour of one of the longest-serving deep-sea submersibles in ocean science



Sail
Known as the sail, this holds the hatch where the pilot and passengers enter the submersible before the pressure hull.

Cameras and lights
High-definition cameras are present on Alvin to record dives, as well as LED lights to light the way.

Thrusters
Seven reversible thrusters power Alvin through the depths of the sea at a cruising speed of around 1.85km/h (1.15mph).

Manipulator arms
Hydraulically powered manipulators allow Alvin to carry out tasks such as collecting samples.

Ballast spheres
The variable ballast system pumps seawater into or out of the tanks to alter the sub's total weight.

Battery tanks
Two battery tanks power Alvin to provide up to six hours of dive time.

Personnel sphere
Alvin's new personnel sphere is larger, with improved ergonomics and five viewing ports.

Sample basket
This allows Alvin to take equipment to its destination, or bring samples and artefacts back to the surface.

4,600+

Number of dives in Alvin's 50-year history

means the pressure equals the weight of an elephant balancing on a postage stamp. To survive that, deep-sea craft need to be extremely tough.

The outer shells of subs and ROVs need to be made of a substance that won't buckle under the astonishing pressure. Titanium is often used, because it's incredibly strong, corrosion resistant and is also able to withstand both the freezing depths of marine trenches and the soaring temperatures of hydrothermal activity.

The pressure hull of a submersible is the area that needs to be hardiest of all, keeping the internal pressure comfortable for human occupation. A sphere is the most common form, as with this specific shape the pressure is applied equally. Many submersibles feature spherical personnel pods constructed of one element, with no joins that may weaken the structure. DOER Marine's Deepsearch submersible employs this technique, with their sphere made out of incredibly tough glass.

One submersible that uses a radically different pressure hull is Virgin Oceanic's sub. This features a cylindrical compartment made of 13-centimetre (5.1-inch) -thick carbon fibre, capped with a see-through viewing dome constructed of incredibly strong synthetic quartz.

Another key element of submersible design is buoyancy. The craft needs to descend, ascend and be able to 'hover' in the water column at the pilot's direction. Many submersibles, both manned and remotely-operated, use water bladders to provide ballast. These can be filled or dumped at will to ensure that the craft can manoeuvre within the water column.

To make submersibles and ROVs float, many possess ceramic spheres filled with air, packed in to their body. The spheres are often fitted alongside syntactic foam, a light substance made of glass microspheres mixed in epoxy resin. These features work alongside the ballast and also function as a safety feature. If the submersible encounters problems at depth, any expendable weight can be dropped and the buoyancy will lift the sub to the surface.

Remotely Operated Vehicles (ROVs) come in many different configurations, with a large range of depth capabilities and uses. Many are used by

Ask an oceanographer

Liz Taylor, president of DOER Marine reveals the challenges of deep-sea exploration

What are the main issues faced by deep-sea exploration today?
We have the capacity and technology to build both manned and unmanned systems that can reliably reach the deepest parts of the ocean. What is lacking is the willingness to effectively fund exploration; for meaningful exploration to occur, we must be willing to accept that not all expeditions will go as predicted. Sometimes, the greatest discoveries are made by accident.

What technology has DOER Marine developed?
We have worked to develop applied science, multi-mission ROVs and submersibles for a broad array of tasks. Our systems are designed to evolve with new technology and client needs. For example, the 6000m [19,685ft] ROV delivered to the University of Hawaii last year supports a variety of disciplines, from backing up the manned submersibles program, to servicing the Station Aloha Ocean Observing System, documenting historic wrecks and old munitions sites as well as carrying out basic geological and biological survey and sampling tasks. It is equipped with HD cameras, supports multiple sensors and has Gigabit Ethernet maximising the data collecting capacity.

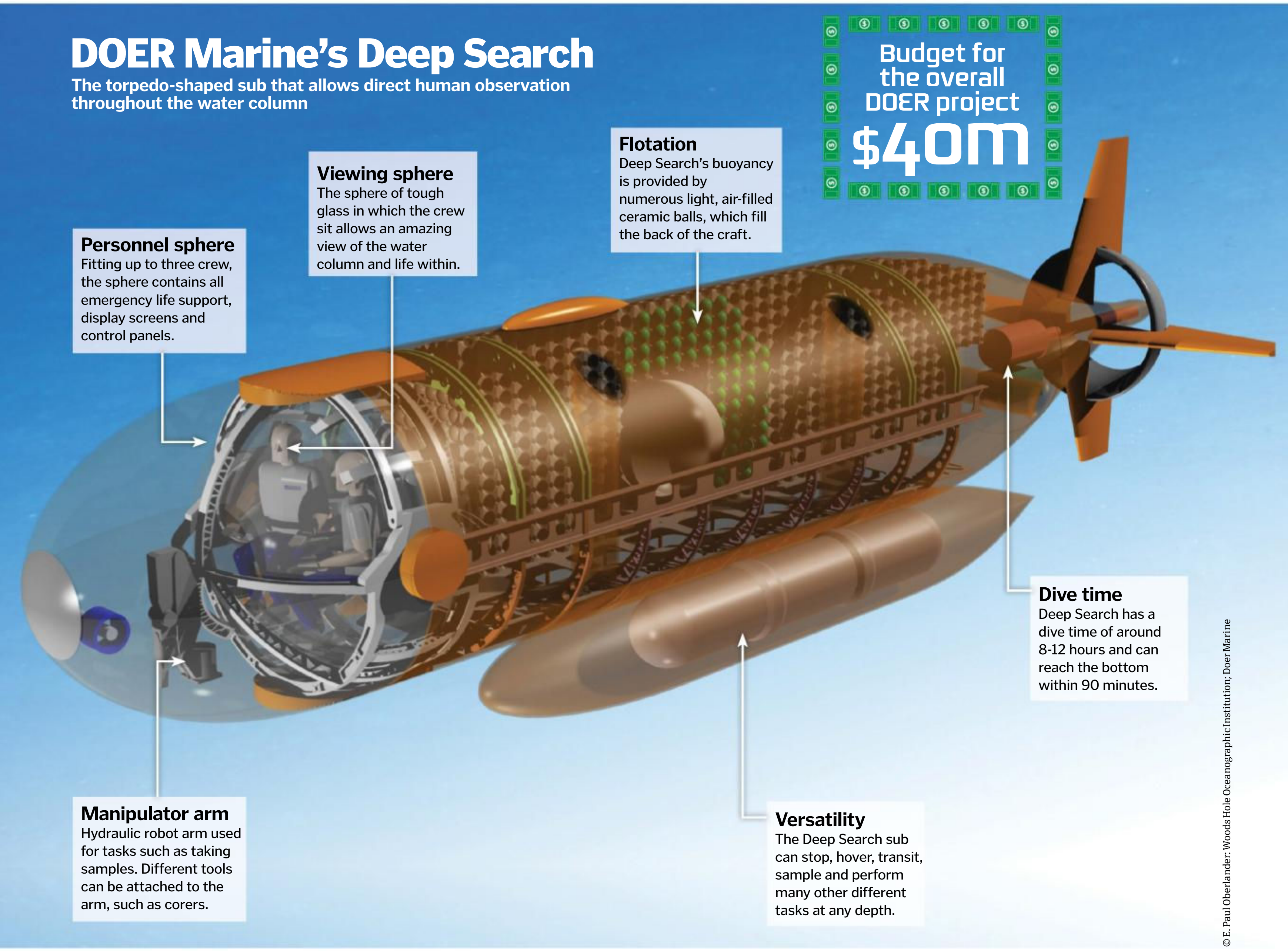
What are the main advancements in the field in the last few years?
The major advances have been in materials science, processing power and reduced size of many components. However, for the human-occupied submersibles, battery technology advances have been a game changer.

What are the major discoveries that new deep-sea technology has helped to unearth?
Some of the most interesting discoveries that have been made have to do with promising new medicines from the sea. Scripps Institute of Oceanography scientists have been working with microbes found to be effective in combating flesh-eating bacteria. The Canadian Cancer Society has funded research involving deep-water sponges. Sponges are also being studied and modelled in artificial kidney research. The biggest discovery, really, is how much more there is still to know about the ocean.

What does the future hold for deep-sea exploration?
There has been much talk about moving toward the exclusive use of robots and sensors [in deep-sea exploration]. However, sensors and drones are great tools to have but they don't possess intuition and they can't act on a hunch. They can't be surprised nor can they return to directly share stories, igniting the imagination and compelling others to care. Knowing what we do now know about the ocean, and its importance to our survival, I think we will continue to "go down to the sea in ships" (and in submersibles) but perhaps more as stewards rather than as despoilers.

DOER Marine's Deep Search

The torpedo-shaped sub that allows direct human observation throughout the water column



the oil industry for drilling support or sub-sea construction, the navy for search and recovery missions and by scientists to explore the ocean and collect data.

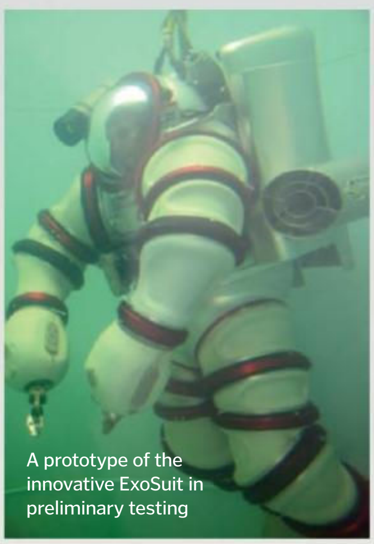
All ROVs have a camera that links a video feed to their parent boat. From here, the operator is then able to guide the vehicle through a task. The robot will often have various highly specialised functions, for example, hydraulically powered manipulator arms that are fully wieldable by the person at the robot's controls. ROVs can be used to accomplish tasks that regular humans simply couldn't do, to be used in the ocean the same way scientists would use rovers and landers in space. Some ROVs operate using a fibre-optic umbilical tether. This connects the robot to the boat and passes information between the control centre and the undersea unit. Using a tether can limit the ROV's depth capabilities, but it also provides a level of security in that the ROV is less easily lost at sea. That is, until the tether becomes tangled or snagged. Other ROV systems are able to operate tether-free, either breaking away from their cable at depth, for example Woods Hole Oceanographic Institution's (WHOI) 'ABE', which stands for Autonomous Benthic Explorer.

The advantage of using a Remotely Operated Vehicle (ROV) to explore the deep ocean, recover shipwrecks or collect samples is that it poses no risk to human life. Removing the human element from the equation also means ROVs are cheaper to build and use.

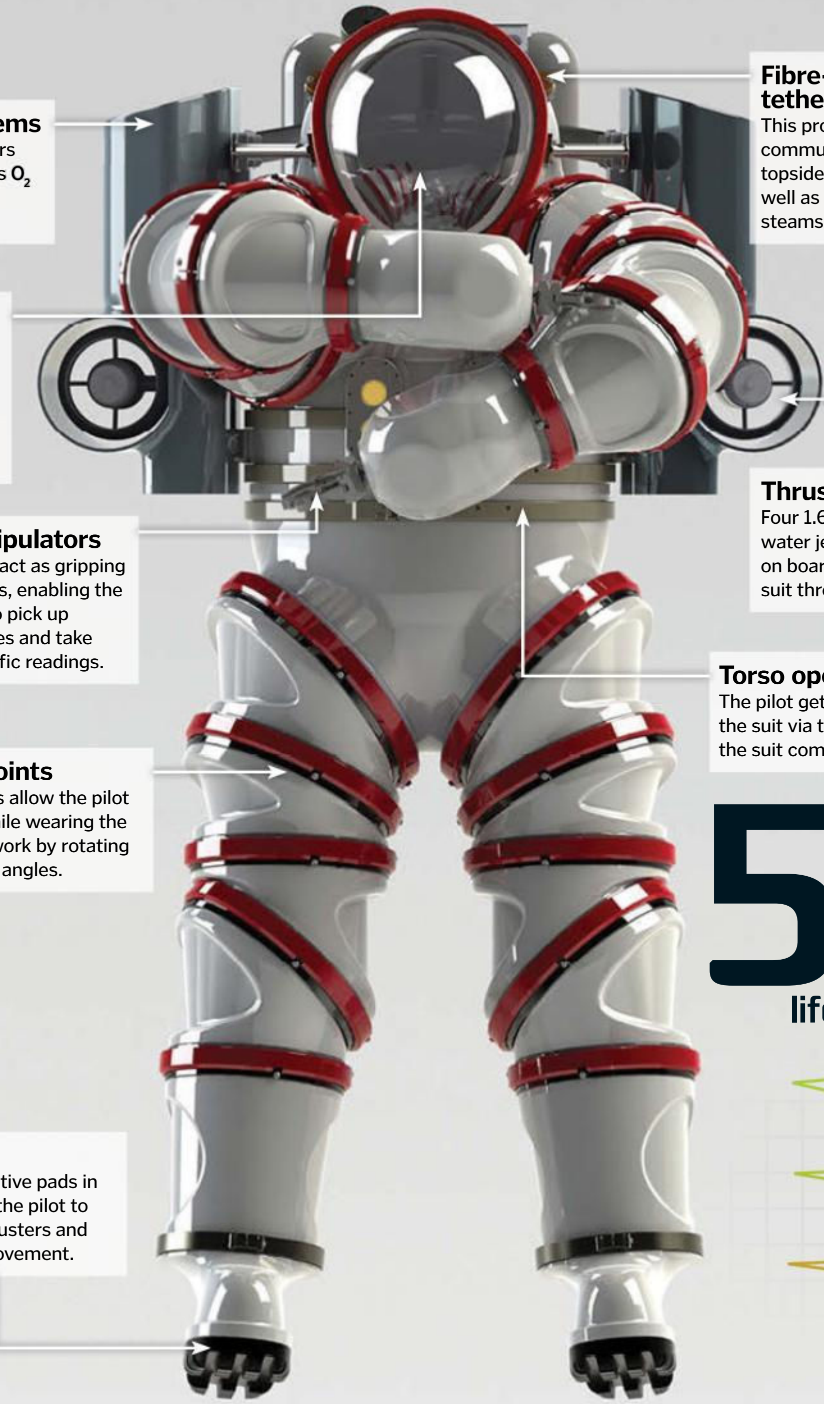
However, many oceanographers argue that the work of a robot underwater is no comparison to the reactions of a human brain. Life support in submersibles is a huge part of their makeup. The pilot and passengers need to be kept at a constant pressure, comfortable temperature and supplied with breathable air. The CO_2 and water vapour exhaled by the crew needs to be removed (this is often achieved using the same method as used on a space ship) and contingency scenarios need to be in place for every conceivable emergency. In James Cameron's Deep Sea Challenger expedition, his pilot sphere was engineered to condense water

Personal deep sea exploration

As mere humans, superpowers are beyond our reach but sometimes technology lets us mimic these powers pretty well. If you've ever dreamt of breathing underwater or exploring the ocean depths without a submersible, then take a look at the Iron Man-esque ExoSuit. With regular SCUBA gear, divers are limited by the effects that pressure has on the human body and by lengthy decompression stops. However this 'wearable' submersible is a suit that can take the pilot from sea level all the way down to a dizzying 305m (1,000ft) in relative comfort, with up to 50 hours of life support. Made of aluminium alloy and weighing in at 250kg (550lb), the astronaut-style suit also has four thrusters to propel it. The suit, working alongside an ROV equipped with cameras and video equipment, will enable marine scientists to get first-hand experience of the life they study beneath the waves.



A prototype of the innovative ExoSuit in preliminary testing



Oxygen systems
With up to 50 hours available, the suit's O_2 stores allow for multiple dives.

Viewing port
The port is teardrop-shaped, allowing a wide field of view down the chest level for the pilot.

Manipulators
These act as gripping devices, enabling the pilot to pick up samples and take scientific readings.

Rotary joints
These joints allow the pilot to move while wearing the suit. They work by rotating at different angles.

Foot pads
Pressure-sensitive pads in the feet allow the pilot to control the thrusters and direction of movement.

Fibre-optic tether
This provides two-way communications with topside scientists as well as live video steams from the suit.

Thrusters
Four 1.6-horsepower water jet thrusters are on board to propel the suit through the water.

Torso opening
The pilot gets in and out of the suit via the torso, where the suit comes apart.

50 hours of life support

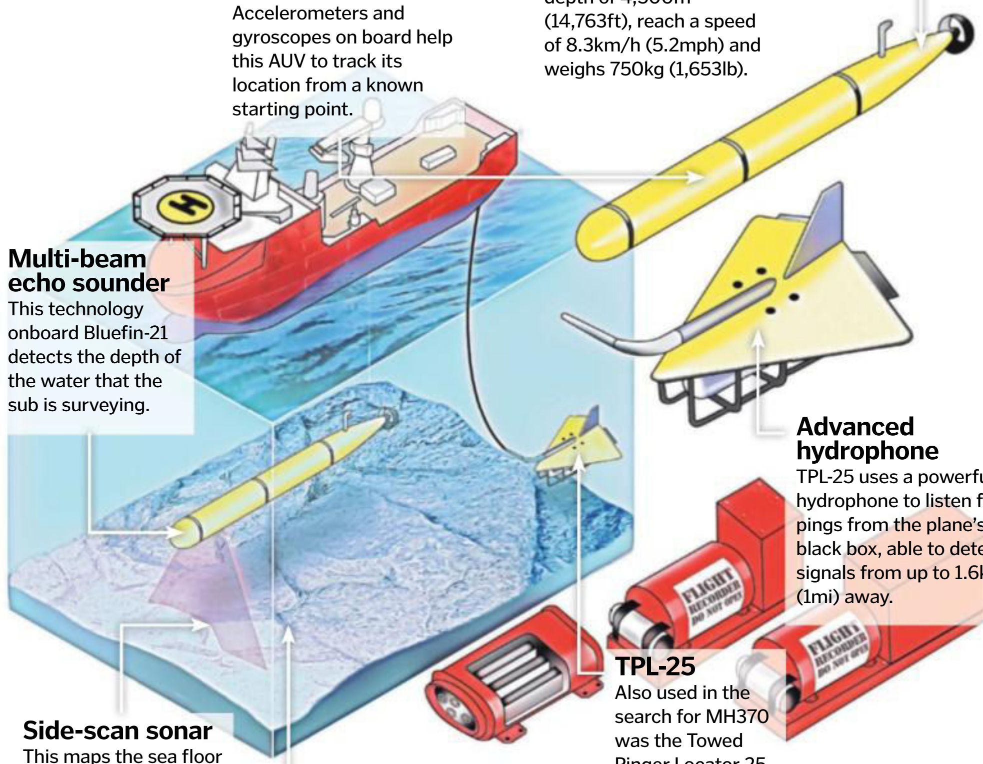
Search and rescue subs

One of the great uses for submersibles and remotely operated vehicles is their ability to go where humans can't, and for long periods of time. This is why they are incredibly useful as search and rescue devices. In the past, the 1966 Woods Hole Oceanographic Institution's DSV (Deep Submergence Vehicle) Alvin was tasked with locating a missing hydrogen bomb, lost in a plane crash in the Mediterranean Sea. Alvin searched for two months before recovering the bomb, complete with attached parachute, under 762m (2,500ft) of water.

A more recent example of submersible search and rescue is the use of autonomous underwater vehicle (AUV) Bluefin-21 in the search for missing plane MH370. On 8 March 2014 a Malaysia Airlines flight from Kuala Lumpur to Beijing disappeared from radar and was presumed to have crashed into the southern Indian Ocean. With such a huge search area to cover in order to find the missing plane, Bluefin-21 was drafted in to help the effort.

The AUV is equipped with side-scan sonar – acoustic technology that creates pictures of the seabed using reflected sound waves instead of light. Bluefin-21 can be programmed to search a particular area, sweeping and scanning 50m (164ft) above the seabed for 24 hours, after which the data can be downloaded and analysed. This creates a 3D map of the area and highlights any wreckage that could potentially be linked to the missing plane.

Unfortunately, despite having scanned over 850km^2 (328mi^2) of the vast search area, at the time of writing Bluefin-21 has yet to locate the missing aircraft.



Navigation system
Accelerometers and gyroscopes on board help this AUV to track its location from a known starting point.

Vital stats
Bluefin 21 can dive to a depth of 4,500m (14,763ft), reach a speed of 8.3km/h (5.2mph) and weighs 750kg (1,653lb).

Multi-beam echo sounder
This technology onboard Bluefin-21 detects the depth of the water that the sub is surveying.

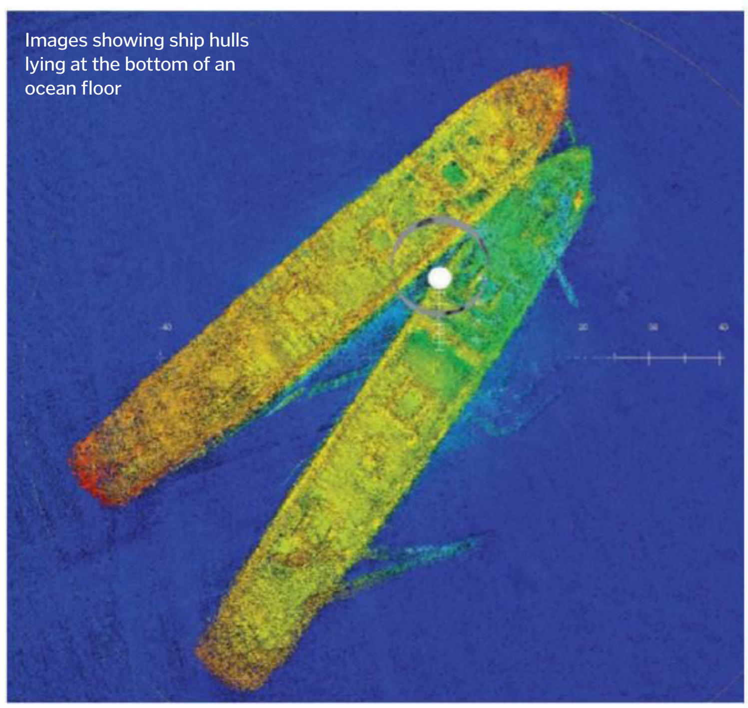
Advanced hydrophone
TPL-25 uses a powerful hydrophone to listen for pings from the plane's black box, able to detect signals from up to 1.6km (1mi) away.

TPL-25
Also used in the search for MH370 was the Towed Pinger Locator 25, towed behind a research vessel.

Side-scan sonar
This maps the sea floor to show if any fuselage has come to rest on the ocean floor.

Distance searched
The TPL-25 system can search an area of over 260km^2 (100mi^2) per day.

The design of Bluefin-21 is reminiscent of a torpedo


Images showing ship hulls lying at the bottom of an ocean floor

vapour and sweat from the pilot into a special bag, which could be drunk in an emergency.

Other types of undersea robots are capable of guiding themselves, after being programmed, to carry out a task. These are known as AUVs, or autonomous underwater vehicles. This kind of mini submarine is used for scanning larger areas of the ocean, as AUVs are able to work for much longer than a manned sub and dive much deeper than an ROV.

One such device is Nereus, owned by WHOI. This is a HROV, (H for Hybrid). The robot can be programmed to venture off alone and scan the sea floor using sonar mapping and camera systems; if it finds anything interesting it can then be returned to the site via a lightweight tether and equipped with extra sampling apparatus at the command of scientists aboard the ship.

A similar method is usually used for other, smaller AUVs such as Bluefin-21, developed by Bluefin Robotics. This AUV is capable of mapping the sea floor using echo sounders and side-scan sonar for up to 24 hours. GPS systems then return it to a parent ship, where the data is then analysed by the scientists.

If anything of interest is found, Bluefin-21 can return to the exact site with high-resolution imaging gear on board to give scientists a closer look. Alongside the external features, submersibles and ROVs require a whole host of other technology on board.

The deepest realms of the ocean are pitch black, so most submersibles and ROVs have powerful lights to provide illumination in the depths. These, as well as everything else on the sub, are battery powered. The battery life of a sub governs exactly how much 'bottom time' is allowed, alongside the ascent and descent rates. Many submersibles still use lead-acid batteries in their power cells, but lithium-ion is now being introduced into many. Stage II of Alvin's latest upgrade is set to see the inclusion of lithium-ion batteries to extensively improve the sub's bottom time.

Typical manned submersibles will have an on-board computer to log data and monitor all electronic systems. As well as GPS and navigational tracking systems, sonar, communications apparatus (Cameron's record-breaking sub could even send text messages), subs and ROVs will also have many different sensors to monitor the parameters outside the craft and send the data back for analysis in real time. Many submersibles and ROVs can also be fitted with all kinds of specialised equipment, depending on the task that it is set to accomplish.

History of deep-sea explorers

Take the plunge into a story of the ever-increasing depths humans have reached

1 Deepsea Challenger
10,908m (35,787ft)

2 Exosuit
305m (1,000ft)

3 Virgin Oceanic
11,034m (36,201ft) (expected)

4 SonSub Innovator
3,000m (9,843ft)

6 Alvin
4,500m (14,764ft)

7 Bluefin-21
4,500m (14,764ft)

8 Shinkai 6500
6,500m (21,325ft)

9 Kaiko 7000II
7,000m (22,966ft)

11 Johnson Sea Link
914m (3,000ft)

12 Seaeye Lynx ROV
1,500m (4,921ft)

13 Deep Worker 3000
1,000m (3,280ft)

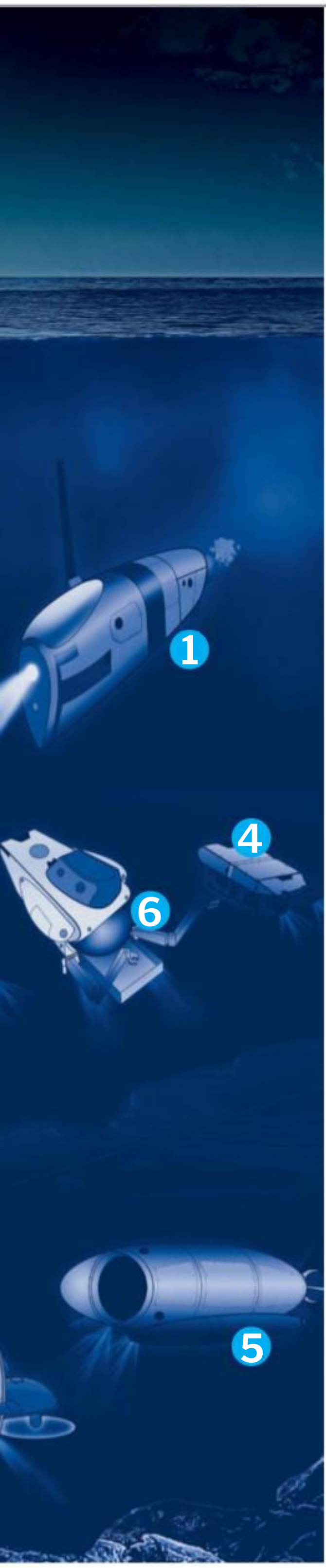
14 Magnum Plus
3,962m (13,000ft)

15 Hercules
4,000m (13,123ft)

16 Sentry
6,000m (19,685ft)

17 MIR DSV
6,000m (19,685ft)

18 Nautile
10,902m (35,768ft)

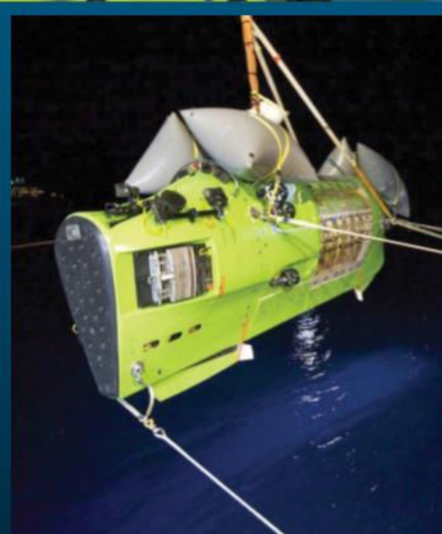


The Challenger Deep revisited

Fast-forward 54 years, and the abyssal Mariana Trench gets her second batch of human visitors. No one had returned since Piccard and Walsh's adventure, until James Cameron completed his Deep Sea Challenger expedition on 26 March 2012.

Deep Sea Challenger is a submersible like no other. Nicknamed a 'giant runner bean', the sub's architecture veers away from the bulky cuboids of standard sub design and is long, thin and descends vertically into the depths. The sub gradually spins on its ascent and descent to keep it on track. The pilot sits inside a tight, spherical cockpit with custom circuit boards powered by large versions of model aeroplane batteries. The exterior has a huge bank of lights to illuminate the voyage.

Cameron descended to 10,908m (35,787ft) armed with high-definition cameras and video equipment alongside state of the art sampling apparatus. Piccard and Walsh were unable to document their dive, but Cameron has more than made up for that, with his feature-length documentary about Deep Sea Challenger set to hit cinemas in the near future.



5 Deepsearch
5,000m (16,404ft)
(expected)

10 Deep Flight Super Falcon Mark II
120m (394ft)

FAR RIGHT It took engineers seven years to develop the sub

RIGHT James Cameron prepares to descend to the Mariana Trench

© Rex features; Peters & Zabransky

XSR48 superboat

The world's first superboat is a £1.2 million masterpiece. As you'd expect, only super-level engineering has been used to create it…

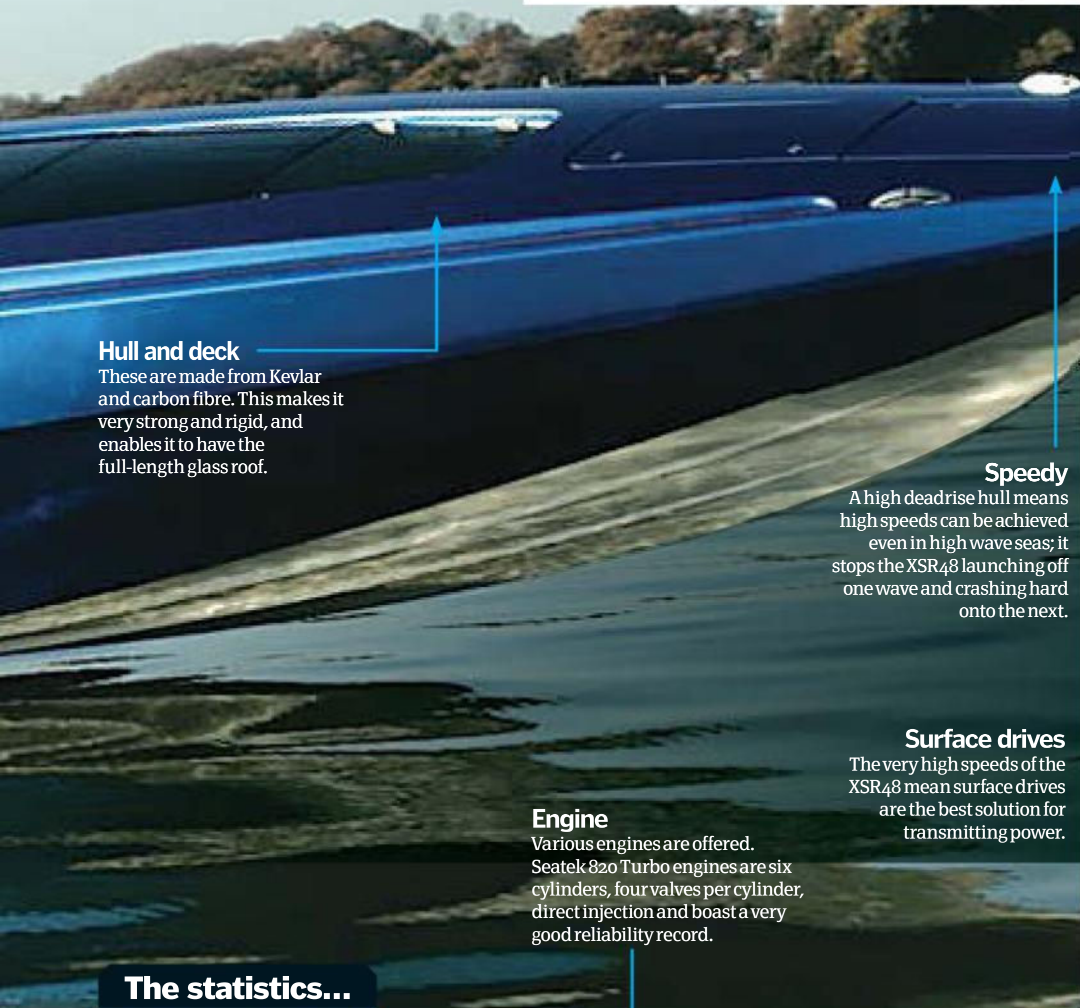
No speedboat like the XSR48 has ever existed. It is such a revolutionary machine, a new term had to be invented: meet the world's first superboat! It is a true groundbreaker. Two world powerboat champions conceived it, and developed it with experts in naval architecture, hydronamics, aerodynamics, aesthetics, ergonomics and propulsion technology.

XSMG used expertise from leading yacht designers and marine structure experts. High power is essential; the minimum output of the XSR48's twin turbodiesel engines is in excess of 1,600bhp. Countries outside Europe can also have supercharged petrol engines that give out well in excess of 2,000bhp. A 1,000-litre fuel tank carries enough diesel for a cruising range of 250 nautical miles – and this is at the XSR's cruising speed of 50-plus knots. That's more than 60mph…

This drive is delivered through a reinforced ZF gearbox to a ZF surface drive system. The surface-piercing propellers are by Rolla and made from stainless steel. Only this sort of system can withstand the potentially crushing forces propellers could be subjected to; XSR has verified this by testing the superboat at speeds in excess of 100mph.

Given such extremes of force, shock mitigation technology had to be standardised in every seat: various configurations of race-style bucket seat are on offer to secure passengers, all of which are fitted with full race harnesses for safety purposes.

It's not all about speed, though. Because it uses a composite monocoque, the additional strength has been used to create more space inside – and the interior is overflowing with luxury. Buyers can choose, for example, a wetroom-style bathroom itself constructed from carbon fibre.



Interior
Car designers who worked for Rolls-Royce, Bugatti and Bentley worked on the boat's interior.

Hull and deck
These are made from Kevlar and carbon fibre. This makes it very strong and rigid, and enables it to have the full-length glass roof.

Speedy
A high deadrise hull means high speeds can be achieved even in high wave seas; it stops the XSR48 launching off one wave and crashing hard onto the next.

Surface drives
The very high speeds of the XSR48 mean surface drives are the best solution for transmitting power.

Engine
Various engines are offered. Seatek 820 Turbo engines are six cylinders, four valves per cylinder, direct injection and boast a very good reliability record.

Interview Ian Sanderson

CEO of XSMG

Described by Jeremy Clarkson as "the most beautiful thing created by man", the idea for the XSR48 came from CEO of XSMG Ian Sanderson. He is a speedboat master, with ten UIM international endurance powerboat records, two world titles and three European titles. "I felt that there was a huge gap in the market for an F1 car-type powerboat that could be positioned as a supercar of the sea. A 'superboat', it would be the marine equivalent of a Bugatti Veyron."

His general intent was to produce a powerboat with the technology, performance and driving experience of an F1 car. To do this, he based it on a hull that, in full racing form, can run at an incredibly impressive 140mph.

> *"I felt that there was a huge gap in the market for an F1 car-type powerboat that could be positioned as a supercar of the sea"*

Sanderson explains carbon fibre monocoque construction was used to lower the centre of gravity, provide massive strength and durability, and increase internal cubic capacity by 40 per cent compared to traditional designs. This means the cockpit and cabin are larger, fuel tanks bigger – even comfort is improved, as more equipment such as fridges and air conditioning units can be fitted.

"The hull has three transverse steps that introduce air under the boat to help her break away from the friction of the water. At each step, the V-shape of the hull is decreased from bow to stern. This means that the hull has a deep sharp V at the bow, which cuts through the waves and the back the boat runs on at high speed."

The statistics...

XSR superboat

Manufacturer: XSMG World

Unit price: £1.2 million

Dimensions: Length: 14.6m, beam: 3.19m, height overall: 3.1m, height above water: 2.2m

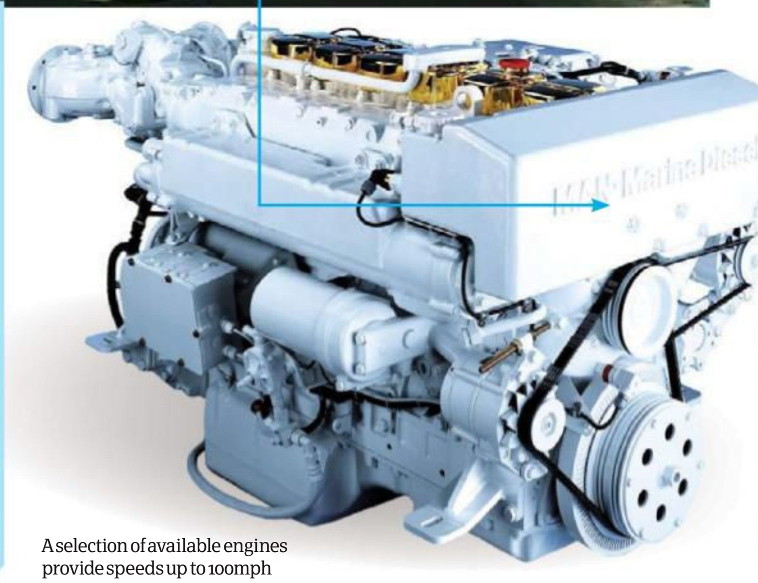
Displacement: 8,750kg

Engine: Two 10.3 L Seatek 820 Plus Turbo – 603 kW

Fuel: Diesel, capacity 1,000 litres

Top speed: 70 knots

Horsepower: 1,640bhp (standard), 1,900bhp (max)



A selection of available engines provide speeds up to 100mph

Hovercraft

How do these incredible machines traverse both land and sea?

The ability of hovercraft to cross dry land as well as water has seen them employed in the military and tourism sectors for many years. Although once billed as the next generation of transportation, they have somewhat declined in popularity over the last decade. Despite this, their usefulness is still readily apparent.

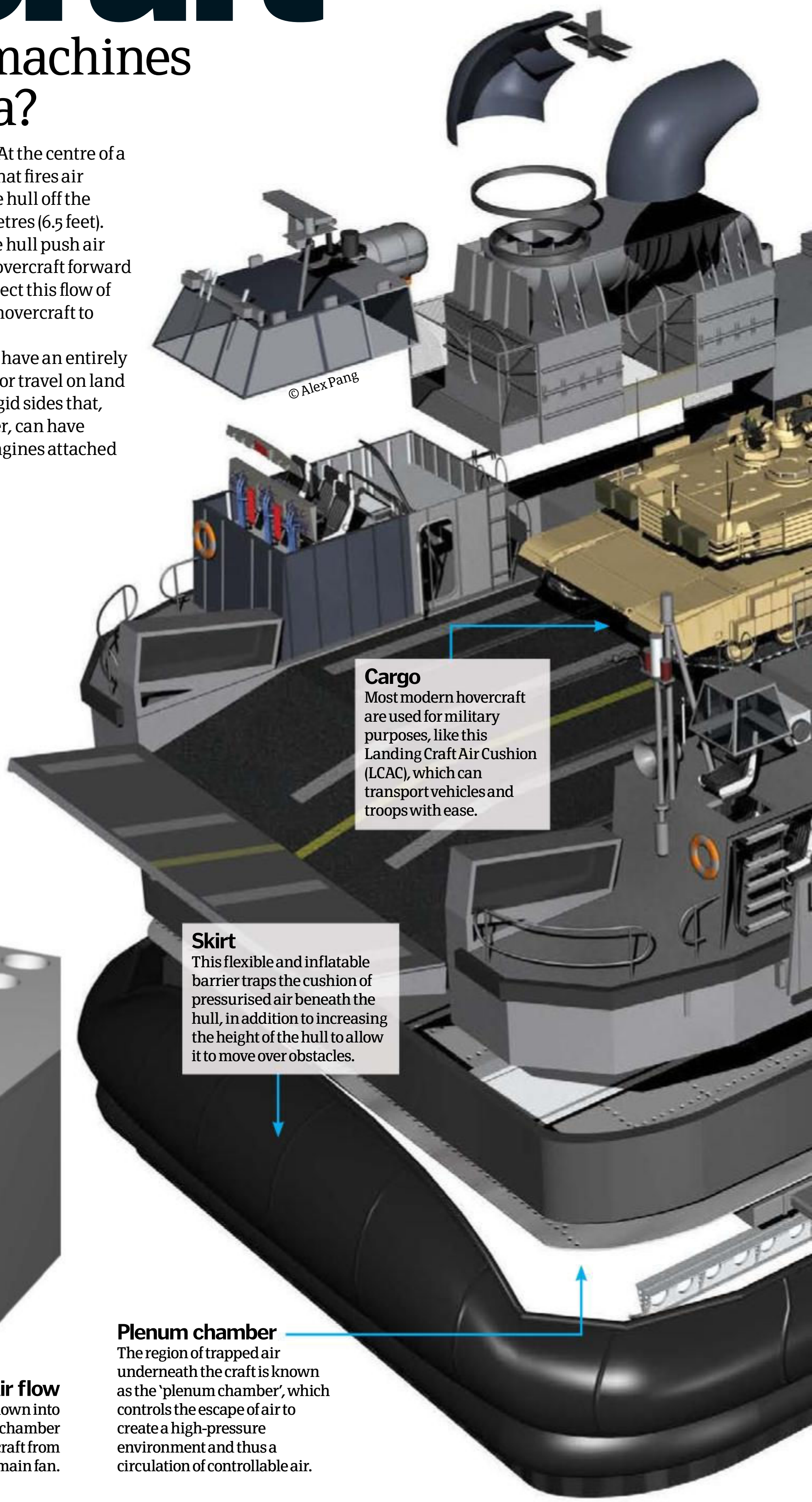
The core principle of a hovercraft is that the hull of the vehicle is suspended on top of a giant cushion of air, held in place by flexible rubber that allows it to traverse difficult terrain or choppy waves without being torn apart.

So how do they work? At the centre of a hovercraft is a huge fan that fires air downwards, pushing the hull off the ground as high as two metres (6.5 feet). Smaller fans on top of the hull push air backwards, giving the hovercraft forward momentum. Rudders direct this flow of horizontal air to allow a hovercraft to change its direction.

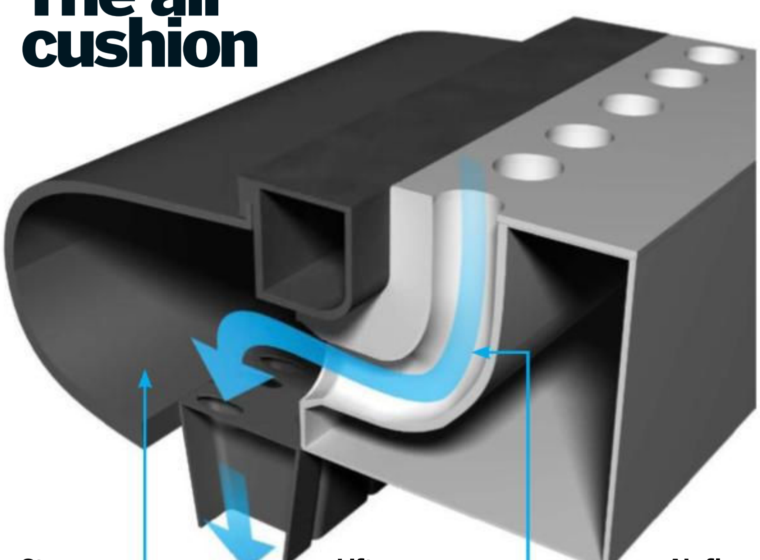
Traditional hovercraft have an entirely rubber base that allows for travel on land or sea, but others have rigid sides that, while suited only to water, can have propellers or water-jet engines attached for a quieter craft.

Hovercraft have been in use for over 50 years

© Andrew Berridge

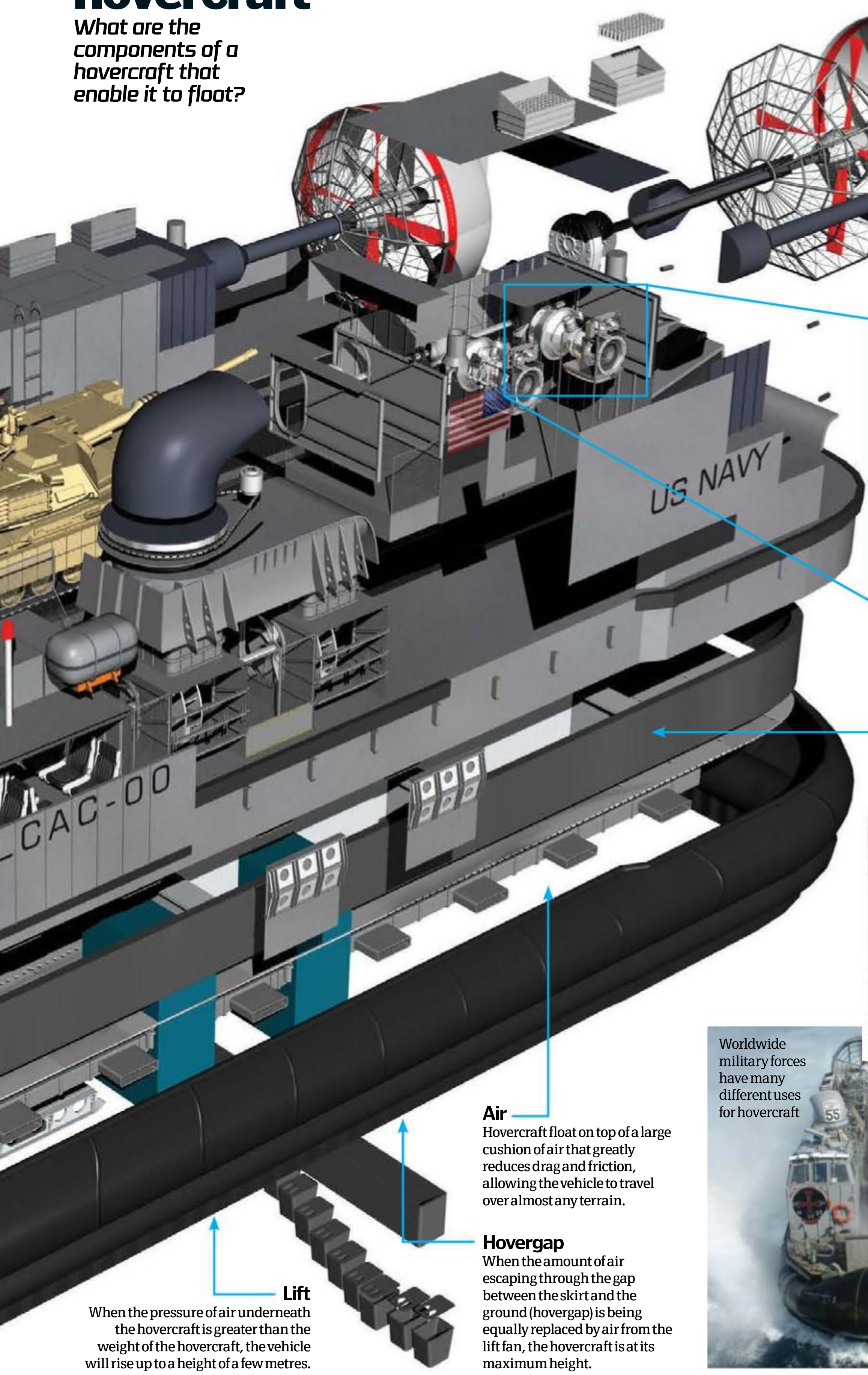


The air cushion



Inside an LCAC hovercraft

What are the components of a hovercraft that enable it to float?

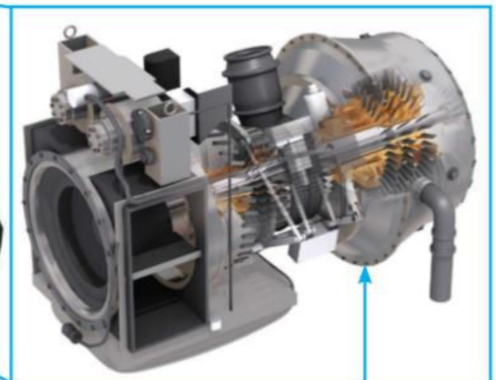


Rudders

Flaps at the back control the hovercraft like an aircraft, directing airflow in certain directions to allow it to be steered.

Thrust fans

The hovercraft gains its propulsion from these backwards-facing fans, normally mounted on the back of the vehicle. Some use ducted fans while others favour naked propellers.



Lift fan

Air is pumped into the plenum chamber by the main fan in the centre of a hovercraft. Although some hovercraft divert air from the thrust fans instead, lift fan designs are much easier to construct.

Hull

The hull is where you'll find the driver, passengers and cargo of the hovercraft. It sits on top of the cushion of air that keeps the vehicle aloft.

Air

Hovercraft float on top of a large cushion of air that greatly reduces drag and friction, allowing the vehicle to travel over almost any terrain.

Hovergap

When the amount of air escaping through the gap between the skirt and the ground (hovergap) is being equally replaced by air from the lift fan, the hovercraft is at its maximum height.

Lift

When the pressure of air underneath the hovercraft is greater than the weight of the hovercraft, the vehicle will rise up to a height of a few metres.

Smaller hovercraft use mostly the same techniques as their larger brothers

© Ankara

Worldwide military forces have many different uses for hovercraft

Supertankers explained

These floating oil fields carry the energy needs of a nation in their ample bellies

The world thirsts for oil. Every day our cars, trucks, furnaces and planes drink up 85 million barrels of crude oil in the form of gasoline, diesel fuel, kerosene, jet fuel and dozens of useful petroleum by-products including that Vaseline you rubbed on your lips this morning. Try to imagine what 85 million steel drums of oil look like – and that's one single day. While Europe and North America remain the largest consumers of oil, our addiction to energy is now a global phenomenon. There is only one way to transport millions of barrels of black gold from the rich oil fields of Russia and Saudi Arabia to the US, Japan and beyond: within the bellies of the largest ships in the world.

Supertankers are high-seas oil tankers that have been supersized to satisfy our colossal modern energy appetite. The biggest of these floating behemoths can carry the equivalent of over 3 million barrels of crude oil in its dozens of below-deck storage tanks; that amounts to more oil than England and Spain consume every day.

Over the course of a year, hundreds of supertankers criss-cross the world's oceans and arctic seas transporting over 2 billion barrels of oil with tremendous efficiency. Second only to oil pipelines, these massive ships cost the equivalent of two US cents per gallon to operate.

That's not to say they're cheap. A brand-new ultra large crude carrier (ULCC) will cost £80-100 million. They are constructed in the goliath shipyards of South Korea and China, which combine to handle over 80 per cent of the world's shipbuilding. Supertankers are welded together from huge prefab structures called megablocks. The vessels are designed with two chief goals in mind: to maximise the amount of oil the ship can carry; and get it to its destination safely.

The first way to maximise carrying capacity is to get bigger. The largest supertanker ever to sail the oceans was the Seawise Giant, weighing in at 564,763 deadweight tons (DWT). If you stood the Seawise Giant on its stern, it would be taller than nearly every skyscraper in the world. Today's supertankers hover around the more reasonable, but still gigantic, 300,000 DWT mark.

In addition to sheer size, supertankers maximise their carrying capacity by filling nearly the entire hold with storage tanks. Modern tankers don't carry actual barrels. Oil is pumped from the shore through a system of on-deck pipelines into dozens of below-deck storage tanks. By using many smaller

storage tanks, shipbuilders minimise the effects of sloshing (see 'Slosh dynamics' box). While a smaller tank filled to capacity won't slosh and shift its weight on the high seas, a large, half-empty tank could slosh with enough force to capsize even a supertanker. Once the ship reaches its destination, a powerful on-board pump sucks the oil from the tanks and transports it to an on-shore pipeline, storage facility or to a smaller tanker.

Safety is a major consideration on a supertanker. First and foremost, you are transporting massive quantities of a highly flammable liquid. (Every oil tanker features a large stencilled 'No smoking' sign over the crew quarters!) It turns out that the greatest danger is not the oil itself, but the vapours that can become trapped in the partially filled tanks. That's why modern oil tankers employ an automated inert gas system that fills unused portions of a storage tank with a cocktail of gases that render the vapour inflammable.

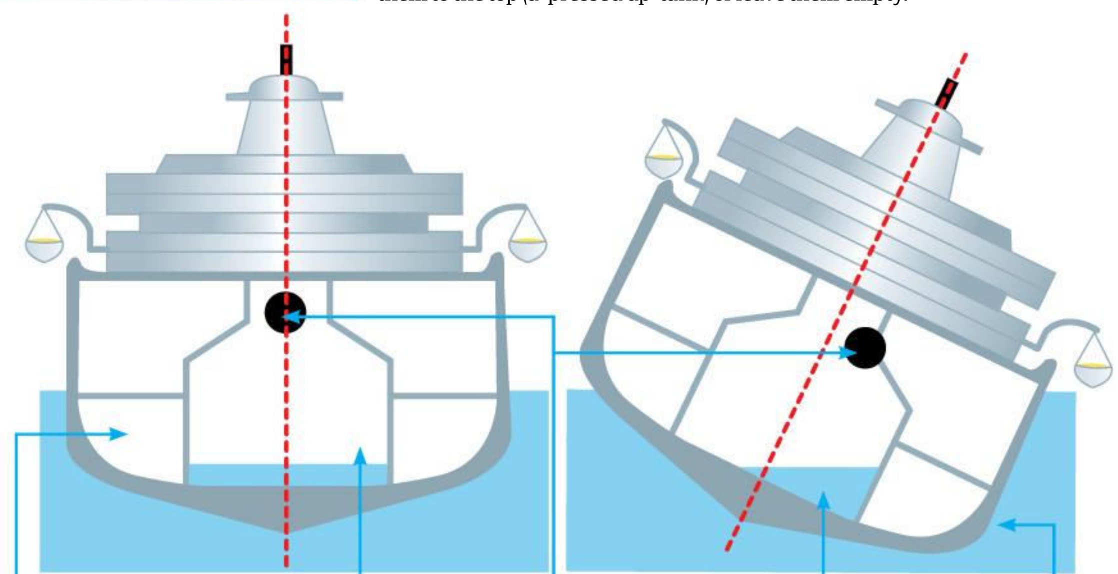
Oil leaks and spills are another big concern, both for economic and environmental reasons. In the wake of the infamous Exxon Valdez oil spill in 1989, all modern oil tankers are required to have double-hull construction. The inner hull containing the storage tanks is protected by an outer hull; these are divided by a three-metre (ten-foot) gap. When the tanker is full, the space between the hulls is left empty, forming an effective crumple zone. When the tanker unburdens its load of oil, the space is filled with water to act as ballast.

Temperature is another serious concern for supertankers. Crude oil and other fuel products can get thick and sticky if they are allowed to become too cold, making them nearly impossible to unload. When supertankers cross through near-frozen arctic waters, they maintain the desired oil temperature by pumping hot steam through coils underneath each storage tank.

A bird's eye view of the prow of an oil tanker

Slosh dynamics

Despite their incredible size and weight, supertankers are surprisingly vulnerable to capsizing. That's because they are filled with liquid cargo, which sloshes about with great force, dangerously altering the ship's centre of gravity. The worst scenario is a large storage tank only partially filled. The liquid in this 'slack tank' will slosh and shift with sudden manoeuvres of the ship or outside forces like strong waves or wind gusts. Since the liquid sloshes in the same direction as the roll, it exaggerates the pitch of the vessel, creating something called the free surface effect. As the vessel tries to right itself to centre, the liquid sloshes even more violently in the opposite direction, initiating a positive feedback loop that can eventually lead to disaster. To mitigate the dangers of the free surface effect, supertankers use several smaller storage tanks and either fill them to the top (a 'pressed up' tank) or leave them empty.



Rocking the boat
The free surface effect can be mitigated by using smaller, off-centre tanks and filling them to capacity.

Slack tank
The free surface effect is exaggerated in a partially filled tank, where liquid moves freely over a large area.

Centre of gravity
If enough liquid sloshes with enough force, it can alter the vessel's centre of gravity and leave the ship unable to right itself.

Slosh
If the ship's manoeuvring or an outside force tips it starboard, the liquid will slosh in the same direction, deepening the roll.

Displacement
Normally, a slight roll is counteracted by the upward pressure of the water displaced. Sloshing liquid acts against that correcting force.

Crude oil is a mixture of compounds known as hydrocarbons

What is crude oil?

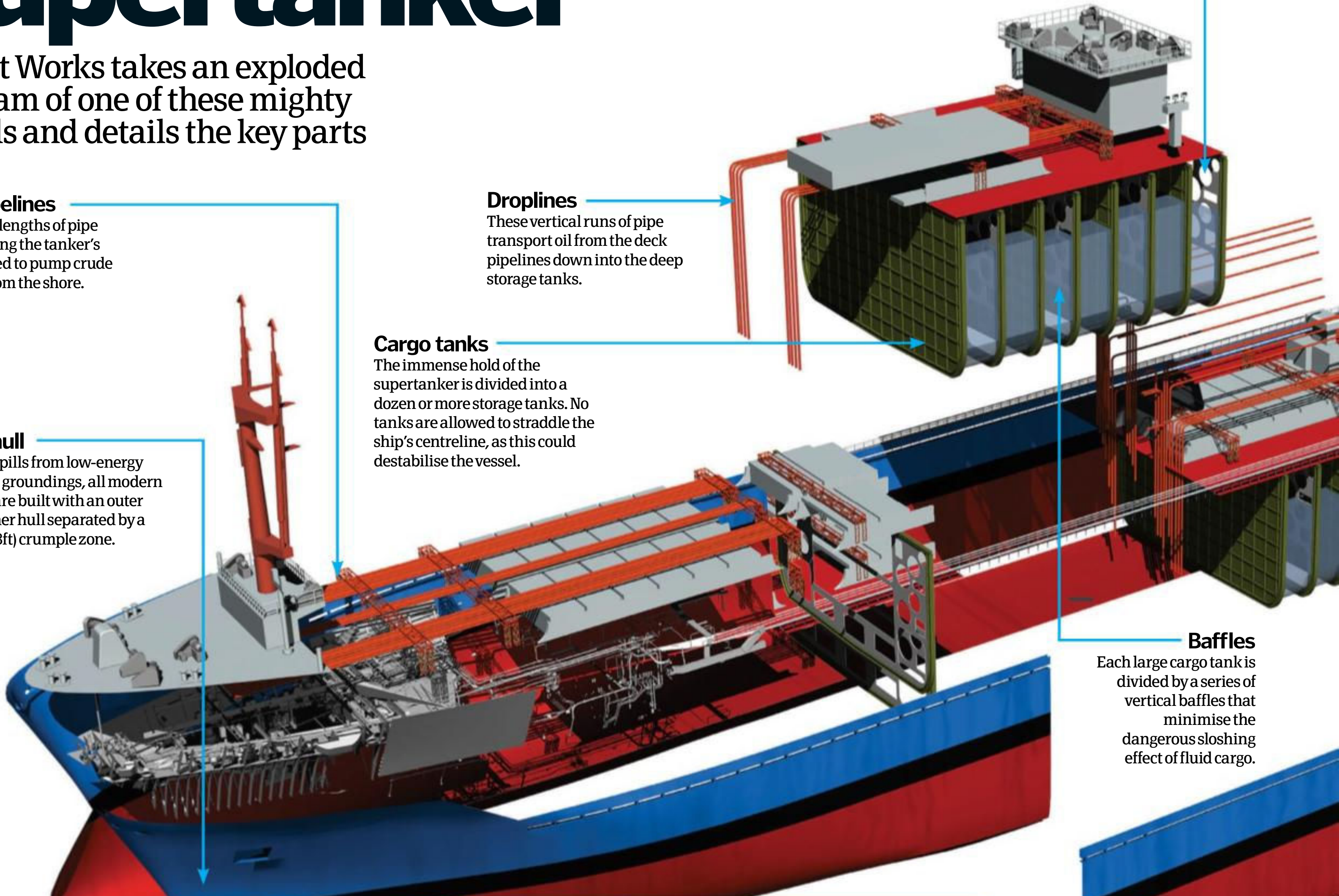
Crude oil is the raw, unprocessed petroleum that is pumped out of the ground through oil drilling. The composition of crude oil varies greatly with the location of the underground oil deposit. The main ingredient of crude oil is carbon, which makes up 83-87 per cent of the mix. There are also natural gases bubbling through the thick liquid such as methane, butane, ethane and propane, composed of hydrogen, nitrogen, oxygen and sulphur in varying quantities. The black/brown crude is shipped to oil refineries, where it is purified and separated into commodities like gasoline, diesel fuel, kerosene and liquid natural gas.

Deadweight tonnage

Following the principle of Archimedes' "Eureka!" moment, if you lower a floating vessel into water, a force called buoyancy pushes upwards on the hull with a force equal to the weight of the water it displaces. Buoyancy only works on objects that are less dense than water. It is the huge volume of air in the hull that allows supertankers to float. Because displacement equals weight, we can figure out the total weight of a ship – known as deadweight tonnage – by measuring the height of the waterline against markers painted on the ship's hull.

Anatomy of a supertanker

How It Works takes an exploded diagram of one of these mighty vessels and details the key parts



Vents
Flammable vapours can build up in the cargo tanks and must be expelled through on-deck venting systems. The vents ensure that vapours aren't released into confined spaces.

Deck pipelines
These fixed lengths of pipe running along the tanker's deck are used to pump crude oil to and from the shore.

Droplines
These vertical runs of pipe transport oil from the deck pipelines down into the deep storage tanks.

Cargo tanks
The immense hold of the supertanker is divided into a dozen or more storage tanks. No tanks are allowed to straddle the ship's centreline, as this could destabilise the vessel.

Double hull
To prevent spills from low-energy collisions or groundings, all modern oil tankers are built with an outer hull and inner hull separated by a 2-3m (6.6-9.8ft) crumple zone.

Baffles
Each large cargo tank is divided by a series of vertical baffles that minimise the dangerous sloshing effect of fluid cargo.

One of the massive storage tanks that can be found on a supertanker

© Science Photo Library

Oil tanker timeline

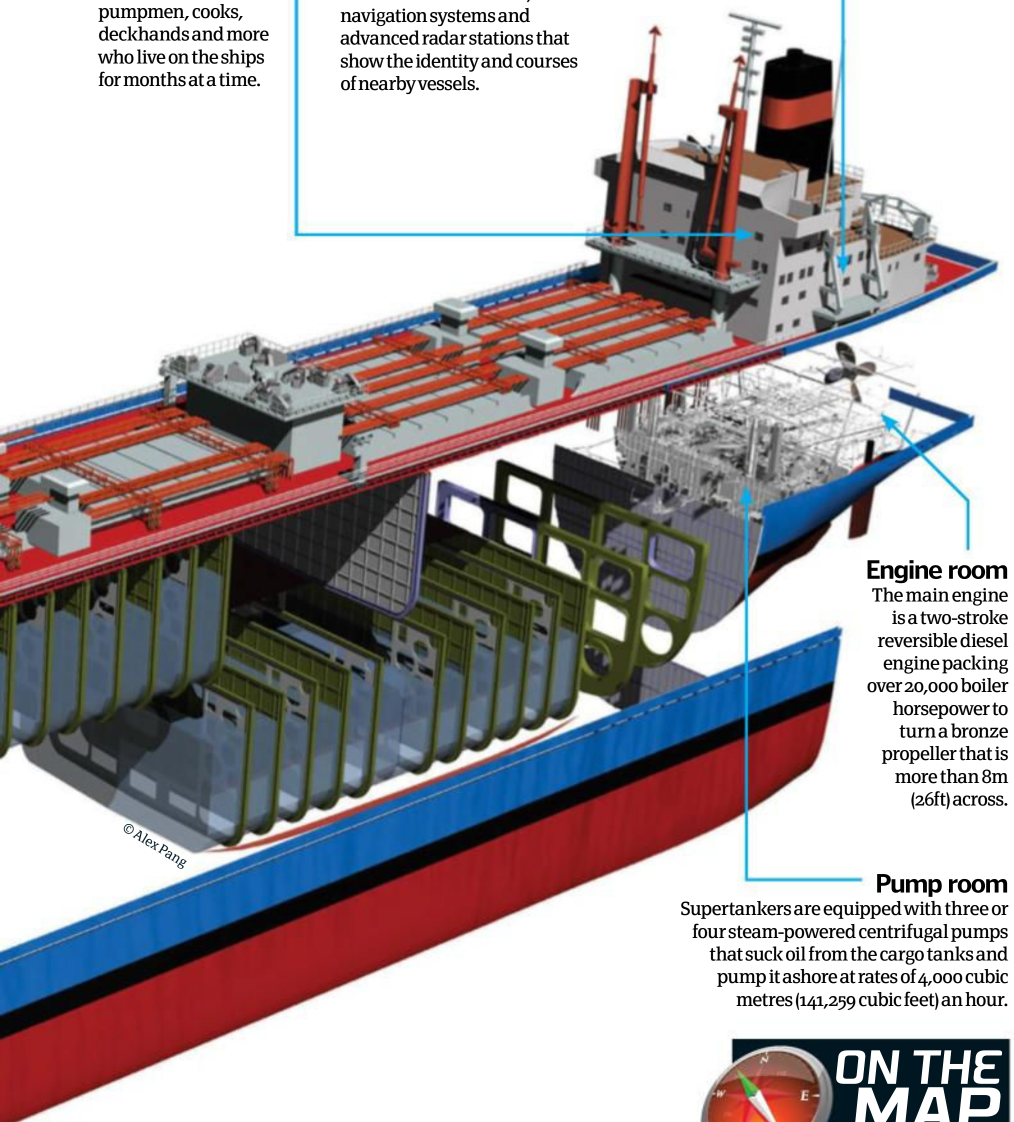
1860s
Wind-powered tankers
A large sailing vessel like the Elizabeth Watts could hold several hundred tons of crude oil, but ocean travel was slow.

1873
First steam tanker
The SS Vaderland is believed to be the first oil tanker powered by a steam engine. They had featured on other types of ship since 1843.

1886
Prototype modern tanker
The British-built Gluckauf was one of the first to have many large, permanent storage tanks in its hold, instead of stacking in barrels.

Crew quarters
Supertankers are manned by skeleton crews of captains, officers, engineers, pumpmen, cooks, deckhands and more who live on the ships for months at a time.

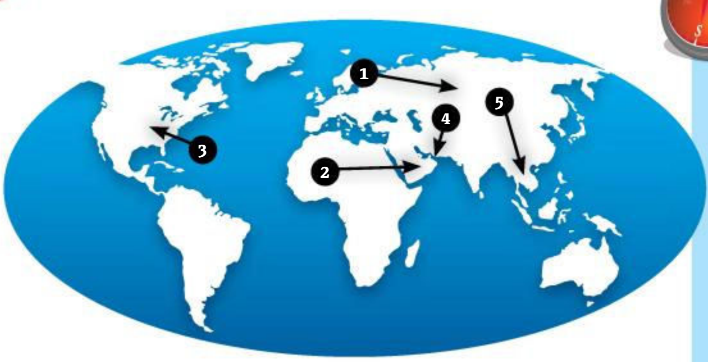
Navigation and communications
Modern supertankers are equipped with satellite communication towers, GPS navigation systems and advanced radar stations that show the identity and courses of nearby vessels.



Engine room
The main engine is a two-stroke reversible diesel engine packing over 20,000 boiler horsepower to turn a bronze propeller that is more than 8m (26ft) across.

Pump room
Supertankers are equipped with three or four steam-powered centrifugal pumps that suck oil from the cargo tanks and pump it ashore at rates of 4,000 cubic metres (141,259 cubic feet) an hour.

ON THE MAP



Top oil producers*

1. **Country:** Russia
   Barrels per day: 9.93m
2. **Country:** Saudi Arabia
   Barrels per day: 9.76m
3. **Country:** United States
   Barrels per day: 9.14m
4. **Country:** Iran
   Barrels per day: 4.17m
5. **Country:** China
   Barrels per day: 4.00m

*Source: US Energy Information Administration

1903
Internal-combustion tankers
Alfred Nobel's brothers, Ludvig and Robert, were oil tanker innovators. The Vandal was their first diesel-electric ship, powered by three 120hp diesel motors.

1915
Wartime refuelling
The USS Maumee was the first large oil tanker used to refuel destroyers on their long Atlantic voyage from America to the UK.

1958
First supertanker
The Japanese-built SS Universe Apollo was the first oil tanker to exceed 100,000 deadweight tons.

Oil tanker classification

Oil tankers come in all sizes. Here we explain the differences and what it takes to qualify as a supertanker

Medium-range tanker

<44,999 DWT (deadweight tons)

According to a system developed by Shell Oil called the average freight weight assessment, oil tankers are classified by the maximum amount of deadweight tons (DWT) they can carry. Medium-range tankers handle up to 44,999 DWT and include the Seawaymax class of tankers, the largest vessels that can pass from the interior Great Lakes of the US-Canadian border to the Atlantic Ocean via the St Lawrence Seaway.

Long-range tanker 1 (LR1)

45,000-79,000 DWT

Tankers classified as LR1 can carry between 45,000 and 79,000 DWT, which may be small on a supertanker scale, however LR1 tankers do have their advantages. For example, no tanker larger than an LR1 can squeeze through the narrow locks of the Panama Canal, which can shave many miles off a journey.

Long-range tanker 2 (LR2)

<160,000 DWT

Some LR2 tankers are twice as large as the heaviest LR1s, reaching a maximum weight of 160,000 DWT. Smaller tankers in the LR2 class roam the waters of shallower sea basins like the North Sea, Black Sea and the Caribbean. The largest LR2s still float shallow enough to pass through the Suez Canal, thus avoiding the long journey around the southern tip of Africa.

Very large crude carrier (VLCC)

<319,999 DWT

From the VLCC class up is officially supertanker territory. VLCCs weigh in at a maximum 319,999 DWT. VLCCs are also known as Malaccamax craft, because they are the largest tankers that can fit through the Strait of Malacca – a 25-metre (82-foot)-deep pass between Malaysia and Sumatra – the most direct sea route from the oil-rich Middle East to oil-hungry China.

Ultra large crude carrier (ULCC)

<500,000 DWT

These gargantuan vessels – more like small, floating nation-states – are the monsters of the supertanker world, with a maximum carrying capacity of 500,000 DWT. The typical ULCC can transport over 3 million barrels of oil, more than the combined daily energy usage of England and Spain. Most ULCCs are too big to fit through canals, so they must take the scenic route around the southern tips of Africa and South America.

How do manned submersibles safely descend to the deadly depths of the oceanic trenches?

Extreme submarines

On 26 March 2012, director James Cameron ascended from the deepest part of the deepest oceanic rift in the world: the Mariana Trench, in the western Pacific. He wasn't the first person to reach the abyssal 11-kilometre (6.8-mile)-deep valley in its floor, the Challenger Deep, and the publicity around the event probably had as much to do with his celebrity status as anything else.

Cameron was actually the third person to go there (after Don Walsh and Jacques Piccard's 1960 descent in the Bathyscaphe Trieste), but he was part of the second manned mission to the Challenger Deep and the first person to reach the bottom of the Mariana Trench solo. And to put all that into better perspective, NASA alone has sent 24 men to the Moon, 12 of them actually leaving their command modules and walking around on its surface, which would have been an impossible feat for this trio of intrepid aquanauts.

So what are the challenges posed by this geological giant, which could swallow Mount Everest and still leave over two kilometres (1.25 miles) of water above its highest peak? The biggest obstacle for any submersible diving to these depths is the extreme pressure. Because seawater has more mass than air per volume – typically 1,025 kilograms per cubic metre (64 pounds per cubic foot) versus 1.23 kilograms per cubic metre (0.08 pounds per cubic foot), for roughly every ten metres (32 feet) you dive into the ocean, the pressure increases by one standard atmosphere (one bar). So the pressure near the bottom of the Challenger Deep exceeds 1,000 bars, or 1,000 kilograms per square centimetre (14,500 pounds per square inch), although temperature and other factors mean this varies.

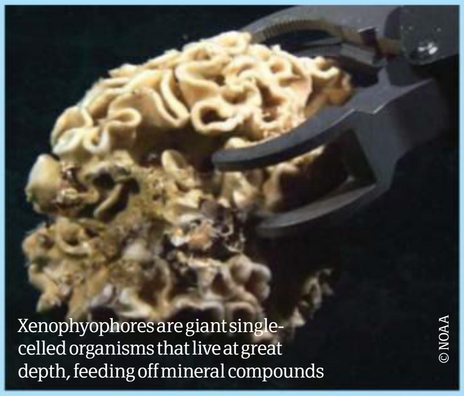
Naturally such extreme pressures would crush us to a pulp, so a manned submersible that visits the Challenger Deep needs to have enormous compressive strength to maintain the habitat inside it, while keeping its human occupants warm and supplying them with breathable air.

Cameron's Deepsea Challenger had a similar structure to the Bathyscaphe Trieste, though its torpedo shape was designed to descend lengthways. At one end is the pilot sphere, the only line of defence against a wall of deadly water. To minimise weight and increase strength, the interior is just 109 centimetres (43 inches) in diameter, while the hull is made of 6.4-centimetre (2.5-inch)-thick steel. The spherical shape of the chamber makes it much stronger; if it was cylindrical like the rest of the sub, it would need to be three times as thick. To facilitate its descent, 450 kilograms (1,000 pounds) of steel

LIFE IN THE TRENCHES

We know very little about life in the deep ocean, but we do know that in the pitch black at the bottom, creatures can thrive. Microbes with the capacity to metabolise the hydrogen sulphide and other compounds that spout from boiling hydrothermal vents form the base of a food chain. In turn this attracts deep-ocean specialised crustaceans, gastropods, worms, eels and more in a place that was, up until the Sixties, thought to be uninhabitable. Incredibly, giant single-cell, amoebic organisms known as xenophyophores are found in their greatest numbers in the oceanic trenches.

Bottom-feeders in the dark regions of the ocean are usually scavengers, feeding off whatever falls from the waters above. But much of the taxa found in the extremes of the deep derive their energy from sources other than the Sun, in an environment that is analogous to those found on other planets in the Solar System. Indeed, extensive studies into these communities has breathed new hope into discovering life elsewhere in the cosmos.



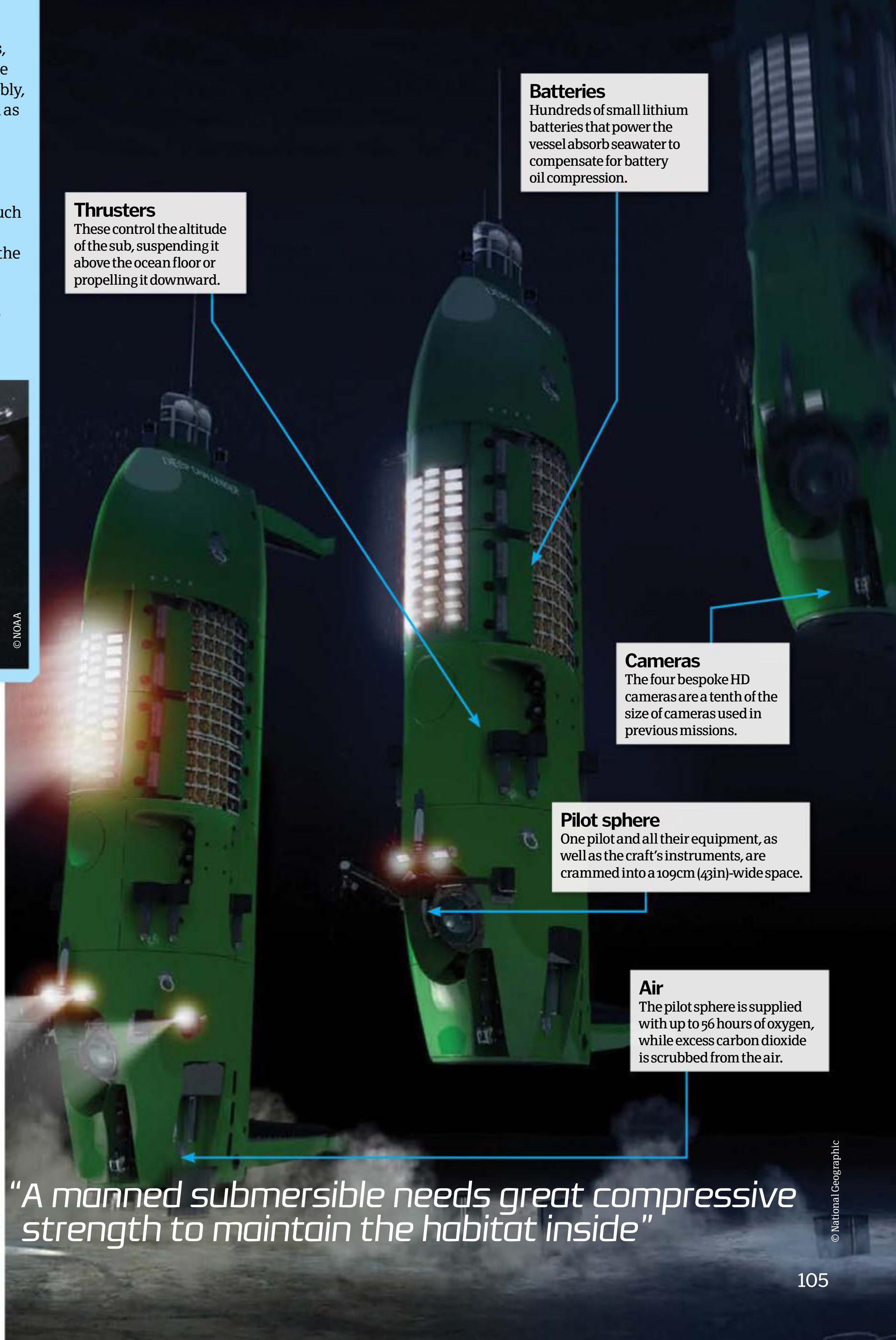
Xenophyophores are giant single-celled organisms that live at great depth, feeding off mineral compounds

weights are held on the side by electromagnets. These are dropped when the pilot needs to rise, but in case they don't (thereby marooning the submersible on the ocean floor), a power failure will drop the weights automatically, the support team on the surface can trigger the command themselves and, as a failsafe, a wire that helps connect the weights to the submersible will corrode and snap after 13 hours' exposure to seawater.

In any case, the Deepsea Challenger uses syntactic foam floats, dense enough to withstand the pressure yet lighter than water – these are able to rapidly lift the craft back to the surface in just half the time it took to reach the bottom.

The Deepsea Challenger

The essential difference between a submersible and a submarine is that a submarine must be able to recycle its own air and power supply, while a submersible relies on a support craft on the surface. This is why military submarines can go for months at sea, while both the Virgin Oceanic and Deepsea Challenger submersibles can only support their pilots for a day or so at most.



"A manned submersible needs great compressive strength to maintain the habitat inside"

Amphibious machines

Take a look at the cutting-edge vehicles that are able to jump between land, water and air as a result of some innovative engineering

The dream of a fully functional amphibious vehicle dates back to the mid-1700s, when an Italian prince drove a modified land/water coach into the Tyrrhenian Sea. Despite the odd universal desire to drive our cars into the nearest lake, only the Amphicar, a steel beauty with stylish tailfins, achieved anything close to commercial success, selling 4,500 units in the Sixties.

Other 'amphibians' have had greater success – namely amphibious aircraft. That's because a simple amphibious plane or helicopter can be made by adding sturdy floats to a pair of landing skids. But amphibious land/water vehicles face many more obstacles, because the engineering rules of the water are often in direct conflict with the rules of the land. For example, a high-speed watercraft needs to break the plane of the water to reduce drag. Picture the wide, hydrodynamic shape of a speedboat hull, which lifts the nose of the boat up and out of the water. The body of a sports car, on the other hand, needs to be low and flat to reduce drag and safely hug the road during sharp turns. So how do you engineer the body of a vehicle that can navigate both surf and turf with ease and speed?

Modern amphibious vehicles have several key advantages over earlier models. Materials, for example. The Amphicar was pure steel, which not only rusts and corrodes, but makes it heavy as a rock. To keep a steel craft afloat, you

The statistics...

Quadski

Crew: 1

Length: 3.2m (10.5ft)

Width: 1.6m (5.2ft)

Height: 1.4m (4.6ft)

Weight: 535kg (1,180lb)

Max land speed: 72km/h (45mph)

Max water speed: 72km/h (45mph)

need a lot of water displacement, which demands a bulky body that looks odd on the road. Today's amphibious cars and ATVs are built from composite material – a strong and lightweight blend of plastics and fibre. These lighter bodies sit higher in the water and require less speed to break the plane.

Propulsion is another huge obstacle. Earlier motorised amphibious vehicles relied on propellers for thrust. Propeller blades had to be small in order to ride high enough on the road to avoid damage, and small propellers provide less thrust. Modern amphibians have switched to water jet propulsion systems with no moving parts outside the craft. Water jets take in water through a hole in the bottom of the hull and use power from the engine to turn a centrifugal pump to build up pressure. The pressurised water is then forced through a nozzle in the rear, providing forward thrust.

The military has always been a great supporter of amphibious vehicles, with landing craft, troop movers and jeeps playing critical strategic roles since World War II. With continued military funding and engineering breakthroughs, we might see a commercially viable amphibious car sooner than you think.

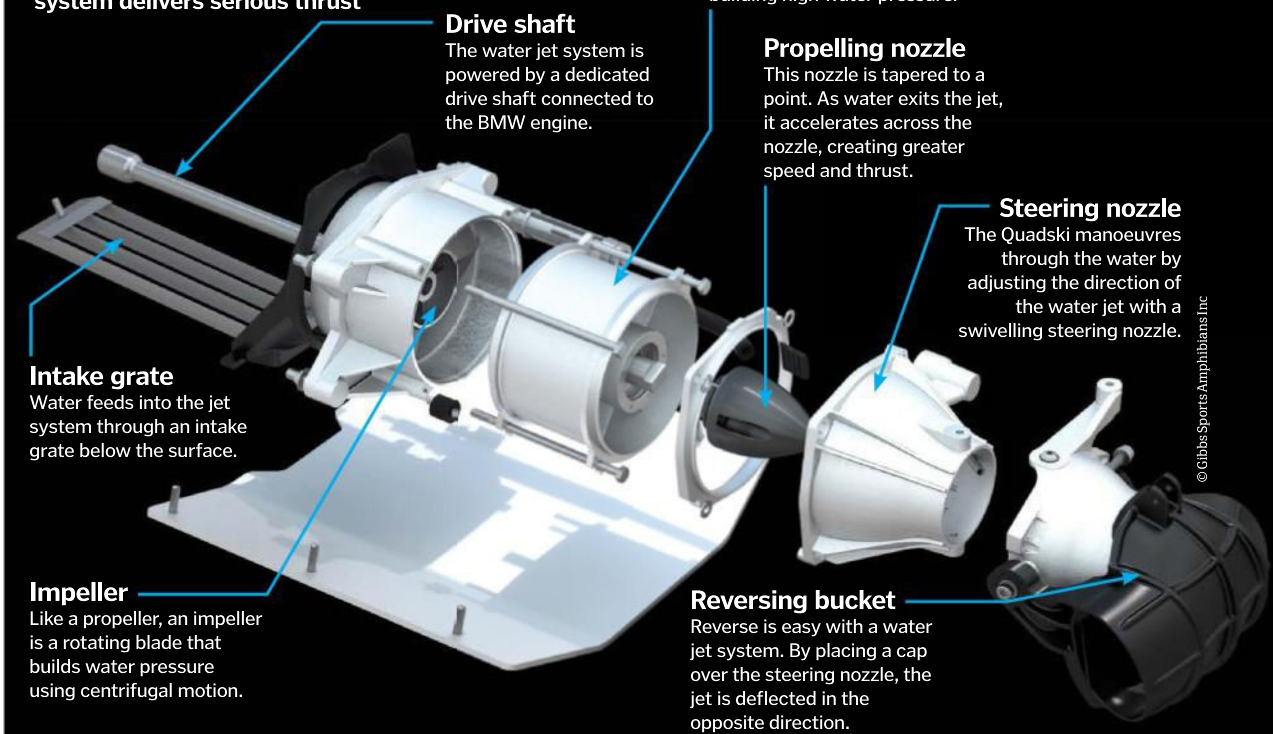
Gibbs Sports Quadski

A quadbike that goes from turf to surf in just five seconds

The Quadski is an amphibious transformer, switching from ATV to jet-ski at the push of a button. The quick-change act centres on the wheels, which fully retract in five seconds thanks to two zippy servomotors. On land, the Quadski looks and rides exactly like a quadbike. For mud-chewing trail rides, the Quadski is powered by the same 130-kilowatt (175-horsepower), 1.3-litre motorcycle engine that supercharges BMW's high-performance racing line. For safety reasons, the engine is capped at 60 kilowatts (80 horsepower) on land, reaching a maximum 72 kilometres (45 miles) per hour. But the real magic is seeing this lightweight ATV move from land to water. Previous amphibian car concepts were literally dead in the water, slogging slow and low. The Quadski, however, leaps out of the water using the full 130 kilowatts (175 horsepower) to pump water through its jet propulsion system. By riding high on the surface on its fibreglass hull, the Quadski can match its maximum land speed on the water.

Jet propulsion up close

The Quadski's compact water jet system delivers serious thrust



Rinspeed sQuba

A James Bond fantasy car brought to life

Rinspeed CEO Frank Rinderknecht had dreamt about an underwater 'flying' car since seeing *The Spy Who Loved Me* in 1977. 007's swimming car was the direct inspiration for the sQuba, a modified Lotus Elise with three battery-powered electric motors and oxygen masks. When the aluminium-bodied, watertight Lotus drives into a lake, it floats. With the flick of a switch, power is diverted to two propellers and two water jets to reach a leisurely surface cruising speed of 5.9 kilometres (3.7 miles) per hour. Getting the sQuba to dive requires driver and passenger to open doors and windows to flood the cabin. To travel at the maximum depth of ten metres (33 feet), the driver must use the water jets. On land, the zero-emissions sQuba can rocket from 0-80 kilometres (0-50 miles) per hour in 5.1 seconds, but maxes out at just 2.9 kilometres (1.8 miles) per hour when underwater.

Dornier Seastar

Land, sea and air: this flying boat's got it all covered

A conventional seaplane is nothing more than a Cessna outfitted with floats. Exposed to seawater, metal seaplanes corrode quickly and require constant maintenance. And without landing gear, they're as waterbound as a tuna. The hull of the speedboat-looking Dornier Seastar, meanwhile, is made entirely of corrosion-proof composite material. For terrestrial destinations, landing gear lowers from the hull. The wide boat hull keeps the craft stable on the water, as does the in-line arrangement of the twin turboprop engines positioned directly over the cabin. The push-pull action of the two propellers can see the Seastar take off – with up to 12 passengers – after just 760 metres (2,500 feet) and reach a maximum air speed of 180 knots (333 kilometres/207 miles per hour). Short takeoffs and landings are aided by two sets of curved sponsons – side projections that add stability to a vessel's hull – located near the middle of the Seastar.

The statistics…

Seastar

Crew: 2
Wingspan: 17.6m (58ft)
Length: 12.5m (41ft)
Height: 4.8m (15.9ft)
Empty weight: 3,289kg (7,250lb)
Max speed: 333km/h (207mph)
Max altitude: 4,572m (15,000ft)

Boat mode
The Seastar is a boat that flies – rather than a plane that floats – so it sits low and steady in the water on its V-shaped hull.

Breaking the plane
Two sets of sponsons make the hull wider under the wings. The sponsons act almost as hydrofoils to raise the hull when moving.

Liftoff
With the nose of the hull out of the water, drag is greatly reduced, so the Seastar can reach takeoff speed in 760m (2,500ft).

Gaining altitude
The push-pull configuration of the twin turboprop engine results in huge thrust so the Seastar can climb 396m (1,300ft) per minute.

Water landing
The sponsons double up as 'water wings'. As the Seastar touches down, the sponsons create just enough drag to slow it.

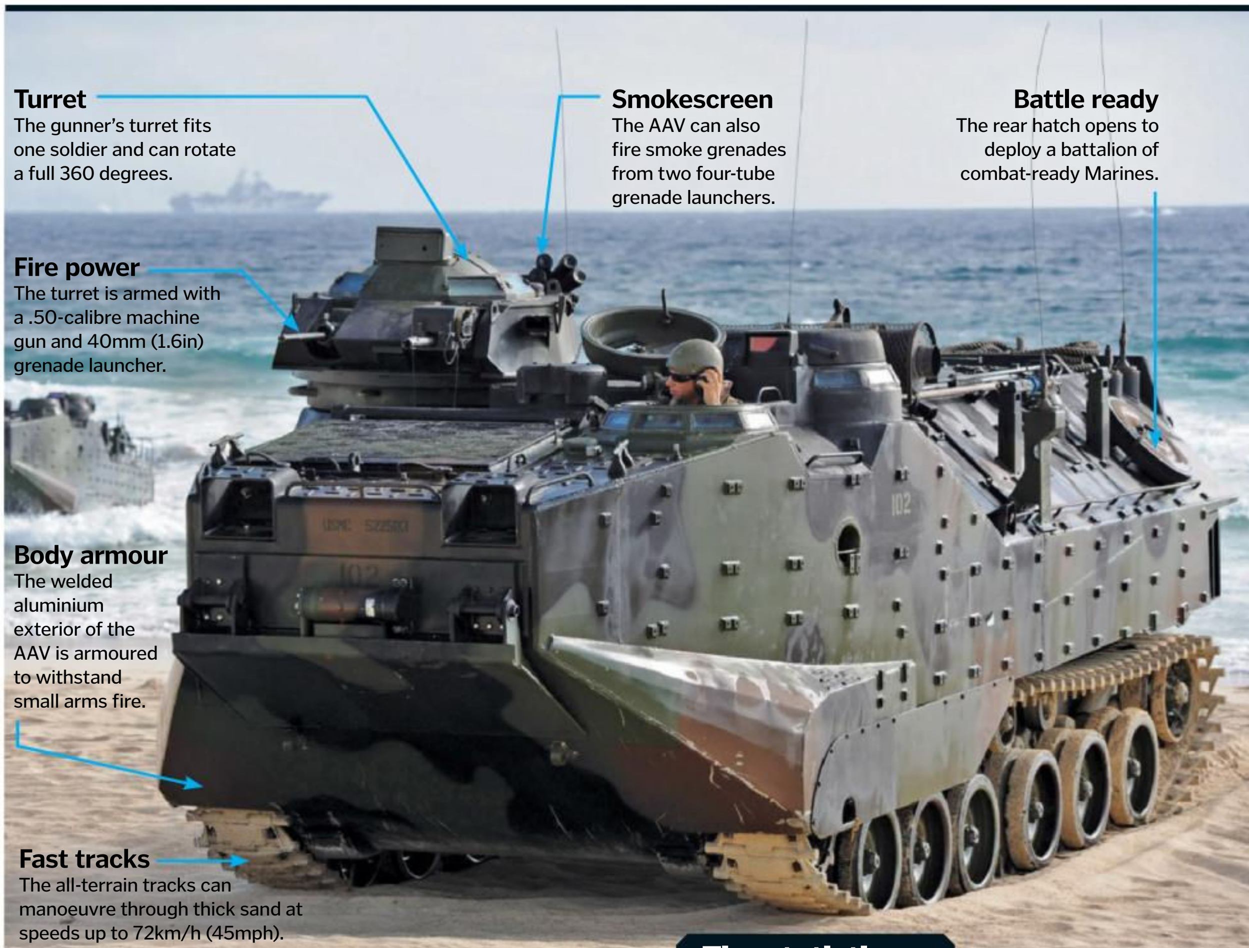
Zero emissions
Rinspeed stripped the Toyota engine from the Lotus Elise and replaced it with three electric motors and six rechargeable lithium-ion batteries.

The statistics...

sQuba

Crew:	2
Length:	3.7m (12.4ft)
Width:	1.9m (6.3ft)
Height:	1.1m (3.6ft)
Empty weight:	920kg (2,028lb)
Max land speed:	120km/h (75mph)
Max underwater speed:	2.9km/h (1.8mph)

Grille gills
When the sQuba floats on the water's surface, the driver can open louvres in the grille to direct water flow toward the rear propellers.



Turret
The gunner's turret fits one soldier and can rotate a full 360 degrees.

Smokescreen
The AAV can also fire smoke grenades from two four-tube grenade launchers.

Battle ready
The rear hatch opens to deploy a battalion of combat-ready Marines.

Fire power
The turret is armed with a .50-calibre machine gun and 40mm (1.6in) grenade launcher.

Body armour
The welded aluminium exterior of the AAV is armoured to withstand small arms fire.

Fast tracks
The all-terrain tracks can manoeuvre through thick sand at speeds up to 72km/h (45mph).

Amphibious Assault Vehicle

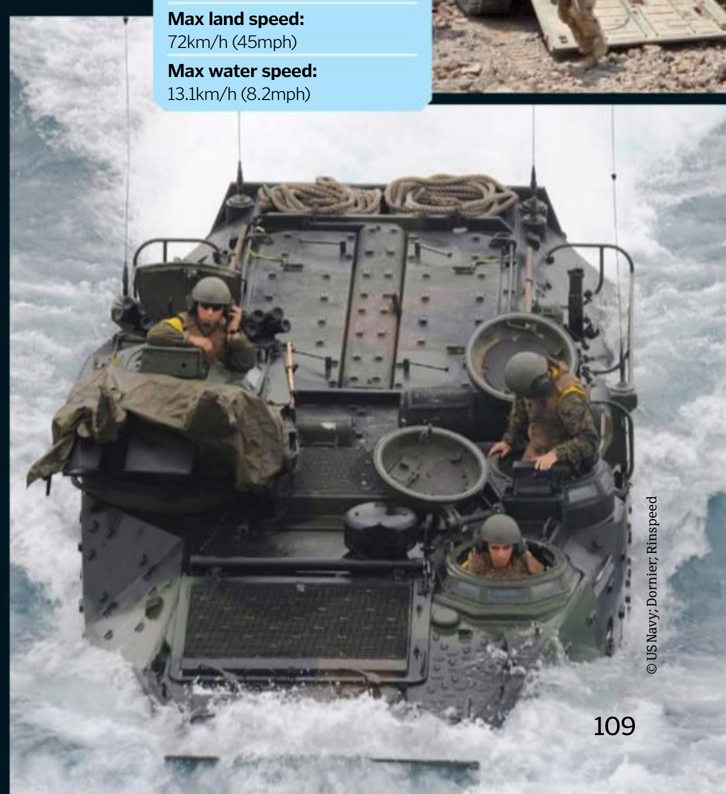
The first to land and the first to fight

Owned by the US Marine Corps, the Amphibious Assault Vehicle (AAV) is a ship-to-shore troop transporter and fully armed combat vehicle. The AAV weighs close to 30 tons and can carry 21 combat-ready Marines and a crew of three. The amphibious tanks launch from the sea-level well decks of assault ships and roar through the water at ten knots (18.5 kilometres/11.5 miles per hour) powered by two rear water jets. The jets are mixed-flow, reversible pumps that propel 52,990 litres (14,000 gallons) of water per minute. In addition to the jets, the AAV gets some propulsion from its spinning tracks. The AAV rides low in the water and can fire its .50-calibre machine gun and 40-millimetre (1.6-inch) grenade launcher on both land or sea. It makes a seamless transition from ocean to shore and carries enough fuel to haul 4,535 kilograms (10,000 pounds) of cargo as far as 480 kilometres (300 miles) inland.

The statistics...

Amphibious Assault Vehicle

Crew:	3
Length:	7.9m (26ft)
Width:	3.3m (10.8ft)
Height:	3.3m (10.8ft)
Weight:	29.1 tons
Max land speed:	72km/h (45mph)
Max water speed:	13.1km/h (8.2mph)



HOW IT WORKS

MILITARY

The machines that shape modern warfare

© BAE Systems/Geoffrey Lee

"Spy planes have become the most feared aircraft"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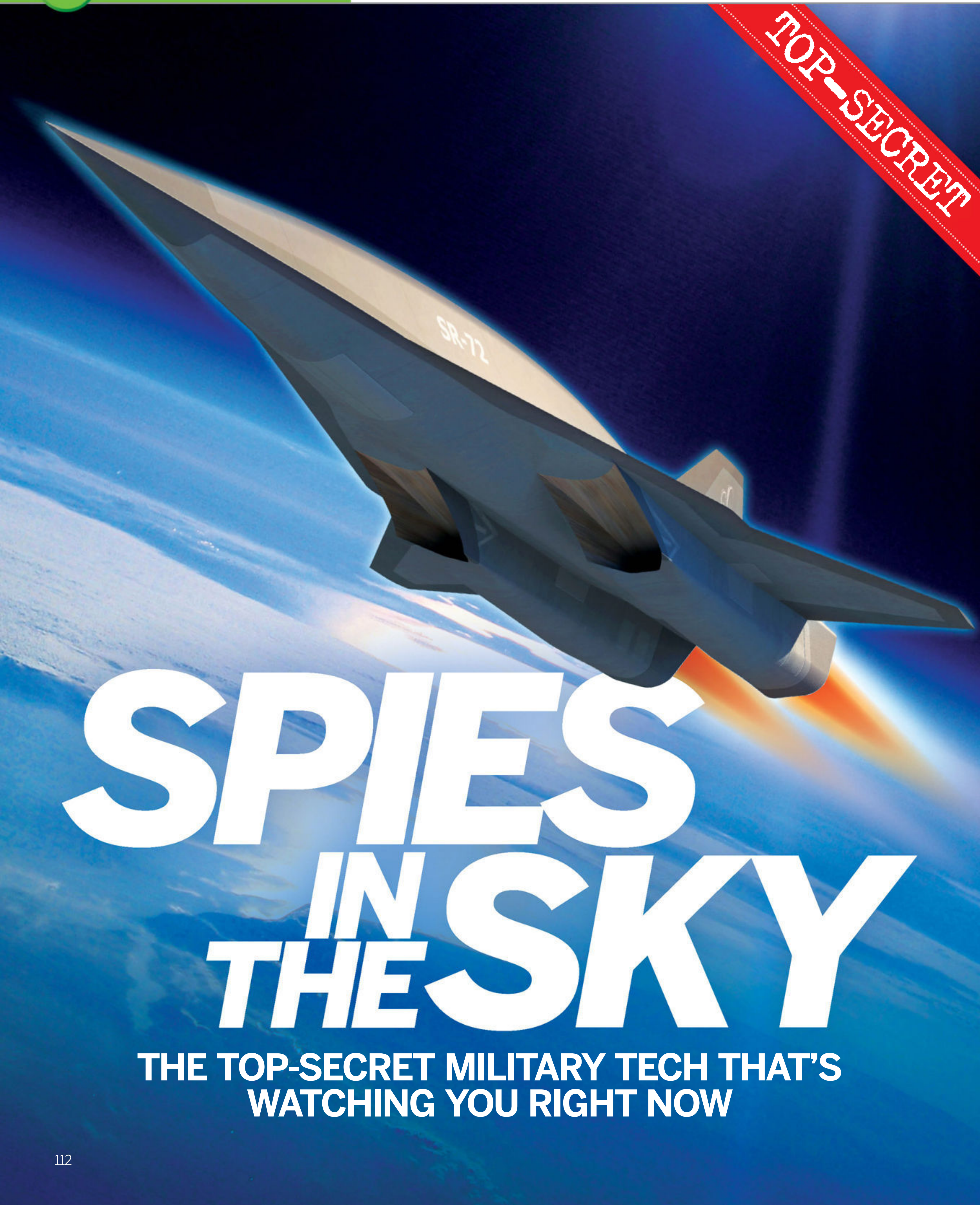


SPIES IN THE SKY

THE TOP-SECRET MILITARY TECH THAT'S WATCHING YOU RIGHT NOW

On 1 May 1954, the Soviet Union's newest bomber – the Myasishchev M-4, nicknamed 'Hammer' – soared above Red Square in Moscow. It wasn't long after the successful detonation of a hydrogen bomb, and the US watched as its former World War II ally turned into a Cold War enemy.

Gaining intelligence was almost impossible, as surveillance planes that tried to enter Soviet airspace were shot down. The Lockheed U-2 would prove to be a complete game-changer. Developed at what went on to become the top secret Area 51 facility, this plane could fly out of reach of enemy fighters and missiles, taking detailed aerial photographs of airfields, factories and shipyards. Knowledge is power, and these images proved to the US that there was no immediate threat and so a deadly arms race – and potential nuclear war – was averted.

Over the course of their history, spy planes have become the most feared aircraft, despite carrying no weapons. Deployed by government and military forces, these eyes in the sky can be used for many different tasks, from patrolling borders and gathering information behind enemy lines, to monitoring battlefields for strategic decision-making.

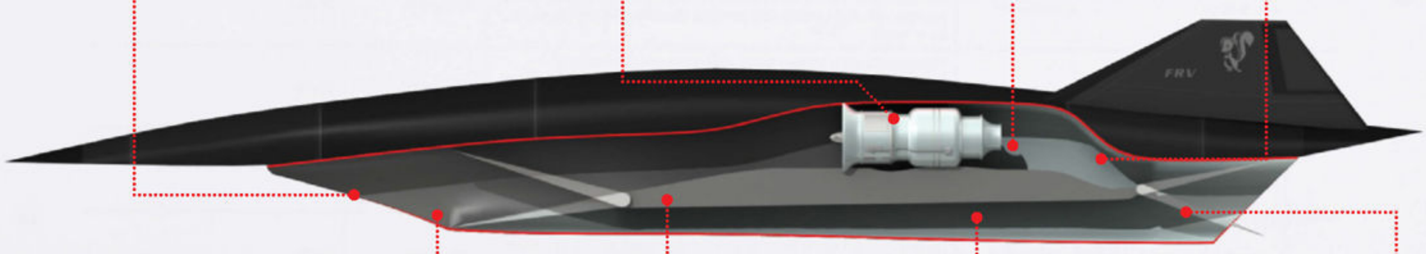
Getting the information they need quickly and discreetly is the key aim for engineers. Modern spy planes use cutting-edge science and technology to do this, but historical planes were able to achieve amazing feats too. One such example is the SR-71 Blackbird. It was built in the analogue age, taking off in 1964 and performing reconnaissance missions until its retirement in 1990.

Despite being 32 metres long with a 17-metre wingspan, this black behemoth could fly faster than a rifle bullet, hitting Mach 3 – three times the speed of sound, over 3,700 kilometres per hour. Its distinctive curved shape with a sharp edge that ran along the body of the plane presented very few surfaces for radar detection, and using

Many technologies invented for the SR-71 are still in use today

Inside the SR-72

Blackbird's successor has a combined cycle propulsion system for reaching hypersonic speeds



Combined cycle
A turbojet engine is combined with a supersonic combustion ramjet engine for optimum performance.

Turbojet
The turbojet engine provides the initial thrust to accelerate the SR-72 from takeoff to Mach 3.

Ramjet force
The ramjet engine then takes over, accelerating the aircraft from Mach 3 up to Mach 5.

Scramjet force
The dual-mode ramjet engine switches to scramjet (supersonic ramjet) mode to accelerate from Mach 5 to Mach 6. It uses supersonic air for combustion to reach speeds of around 7,400km/h.

Common nozzle
The turbojet and ramjet/scramjet engines share an air inlet nozzle to reduce drag.

Air inlet
Air is scooped into the inlet and compressed as it enters the diffuser.

Combustion
Air and fuel are fed into a combustion chamber and ignited.

Thrust
An exhaust nozzle accelerates the burst of expanding hot air, producing a huge amount of thrust.

"Throughout history, spy planes have become the most feared aircraft, despite carrying no weapons"

The SR-72 will reach speeds of Mach 6, double that of its predecessor

top-of-the-range photographic equipment for the time, Blackbird captured images of the ground from an altitude three times the height of Everest. Although some were lost in accidents, none were ever shot down or captured by an enemy.

Now that this godfather of spy planes is out to pasture, Lockheed Martin's Skunk Works division is developing a faster, unmanned successor, the SR-72 (nicknamed the 'Son of the Blackbird'). The engines will use a hybrid system to reach hypersonic speeds, enabling the aircraft to cross an entire continent in an hour. The air friction of this speed alone could melt steel, so the SR-72 is likely to be made of composite materials, similar to those used for space shuttles and missiles. It will need to be capable of withstanding temperatures in excess of 1,000 degrees Celsius and be sealed to stop lethal air leaks.

The technology needed to take photographs at this kind of speed will also be an incredible feat, and the exact makeup of this aircraft's gadgetry has not been confirmed, or perhaps even invented yet. What we do know is that it won't just be an observer. This new unmanned plane will be armed to the teeth, launching bombs to hit targets from altitudes of around 24 kilometres – up in the stratosphere.

Aerodynamics play a huge part in spy plane tech – aircraft like the SR-72 need to be designed to cope with stresses experienced when travelling at such high speeds. The Son of the Blackbird will need to be incredibly well balanced to deal with the changes between subsonic, supersonic and hypersonic flight to ensure that the craft is not ripped apart by the shifting centre of lift.

However, the Global Hawk, for example (an Unmanned Aerial Vehicle made by Northrup Grumman) is nothing like how you might

The SR-71 carried two crew members, but its successor is likely to be unmanned

Boeing Poseidon P-8

This sky-borne sub hunter scans the waters for unwanted aquatic visitors

Based upon the tried-and-tested body of the Boeing 737-800 commercial airliner and the wings of Boeing's 737-900, the Poseidon P-8 is an advanced maritime patrol and reconnaissance aircraft. Featuring all kinds of task-specific technology, the P-8 is able to fly fast and low, cruising above the sea to seek out submarines that can pose threats to aircraft carriers.

Six extra body fuel tanks extend the plane's range to find the subs. Some variants of the Poseidon P-8 model use radar, a magnetic anomaly detector and electronic intelligence sensors to monitor telecommunications and infrared imaging to keep tabs on shipping. It can also deploy expendable sonobuoys to act as satellite sensors in the field.

But that's not all this spy plane can do. With its strengthened fuselage, the Poseidon also boasts missiles, mines and torpedoes in its arsenal, making it ready to aim, fire and dispatch a rebel submarine if ever required.

Weapons bay
The belly of the plane hosts five stations for Mk54 torpedoes and mines.

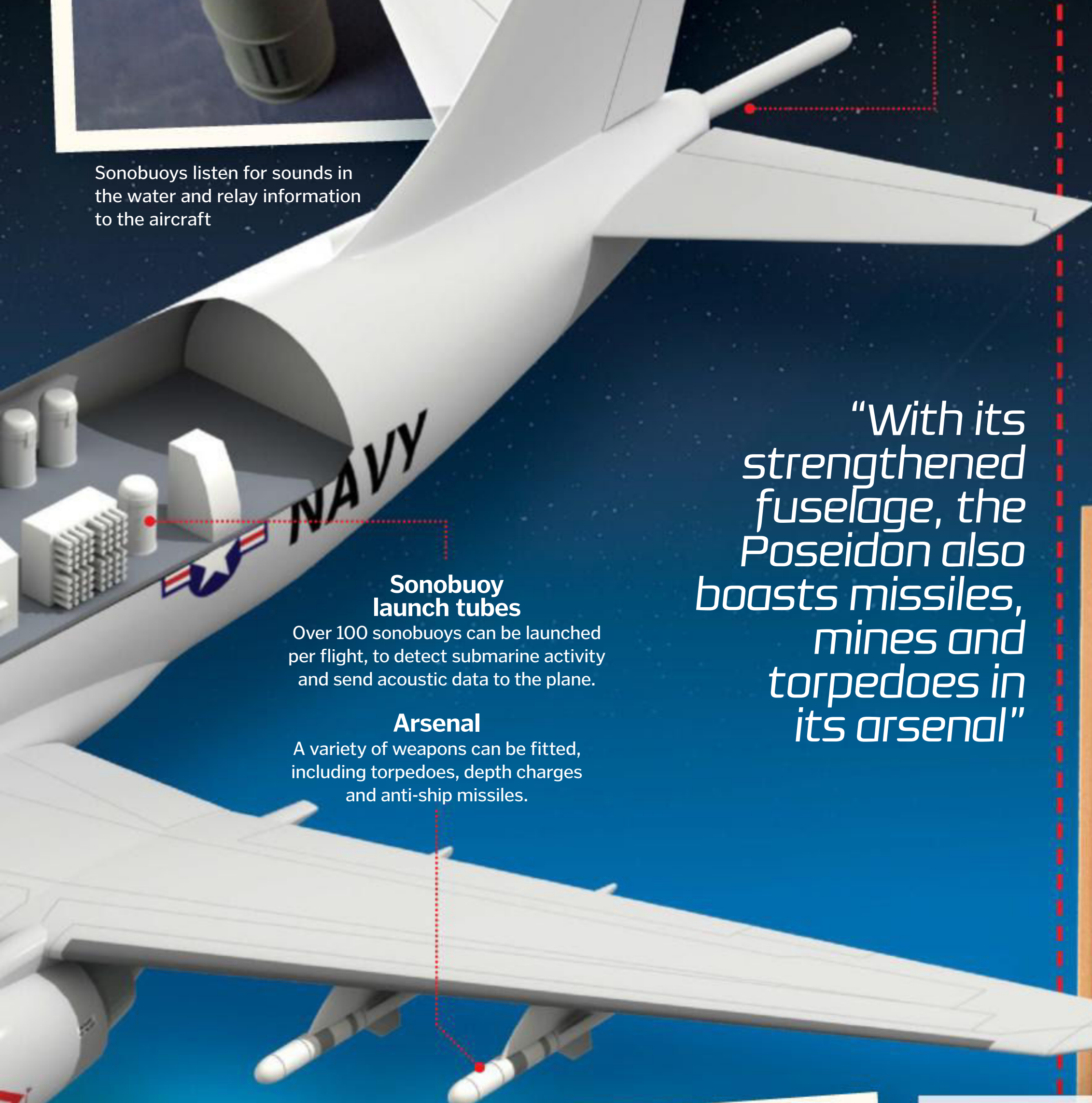
Refuelling
This port makes aerial refuelling possible, extending missions beyond the range a single tank provides.

Engines
Two powerful, fuel-efficient CFM56-7B turbofan engines enable a maximum speed of 907km/h.

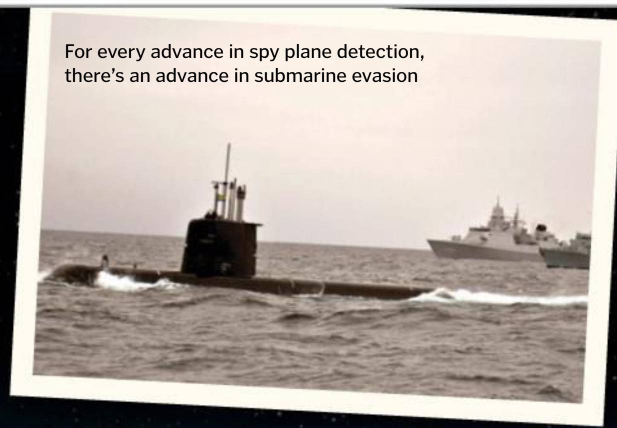
Workstations
High-resolution workstations operate seamlessly with the craft's radar, with all sensors controllable from each station.

Multi-mode radar
Radar detects surface ships and other aircraft, producing ultra-high resolution images in all weather conditions.

Sonobuoys listen for sounds in the water and relay information to the aircraft



"With its strengthened fuselage, the Poseidon also boasts missiles, mines and torpedoes in its arsenal"



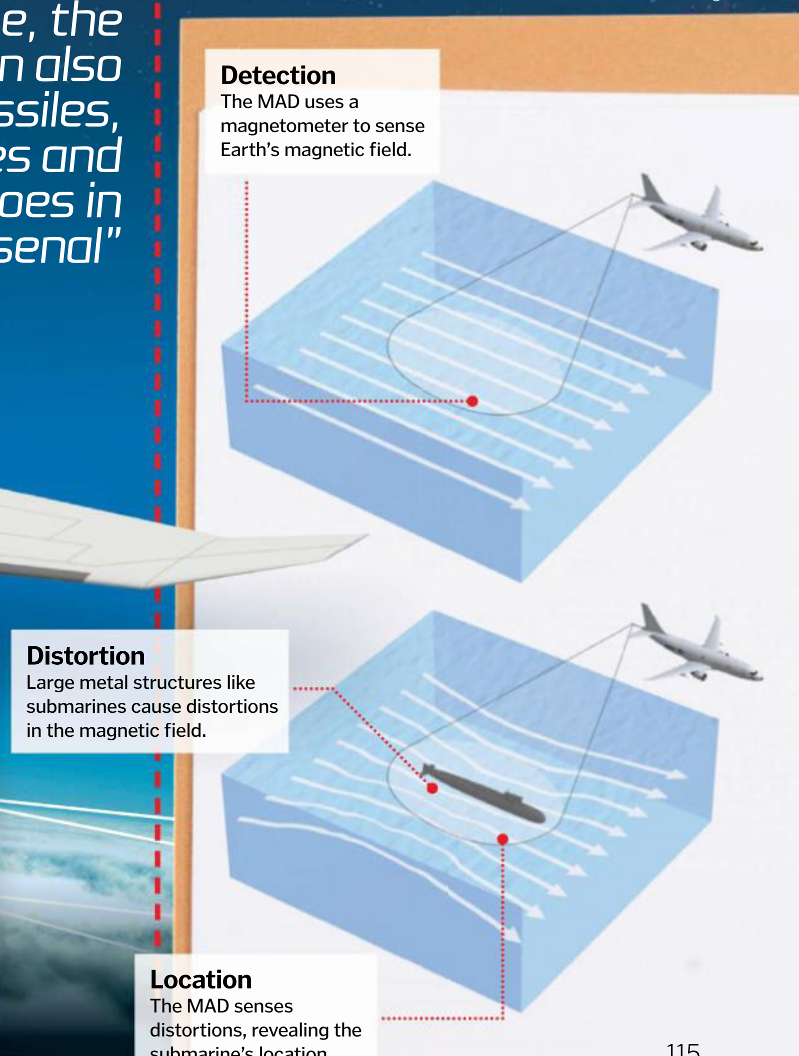
For every advance in spy plane detection, there's an advance in submarine evasion

Stealth subs

You could easily think that, for a giant metal tube in a featureless ocean, there's nowhere to hide. But once again, tech is lending a hand. Where some aircraft use magnetic anomaly detectors to seek out magnetic signatures, submarines will employ 'degaussing' techniques to evade detection. This involves using electromagnets to create another magnetic field that matches the background field, rendering the signature undetectable.

Another stealth method is to deflect sonar. Coating materials modify the sound waves hitting a submarine so that they don't bounce back. Such materials in development include a substance that 'wicks' sound waves off a sub like water off a duck's back, as well as a material that looks like miniature bubble wrap, which soaks up and disperses sound.

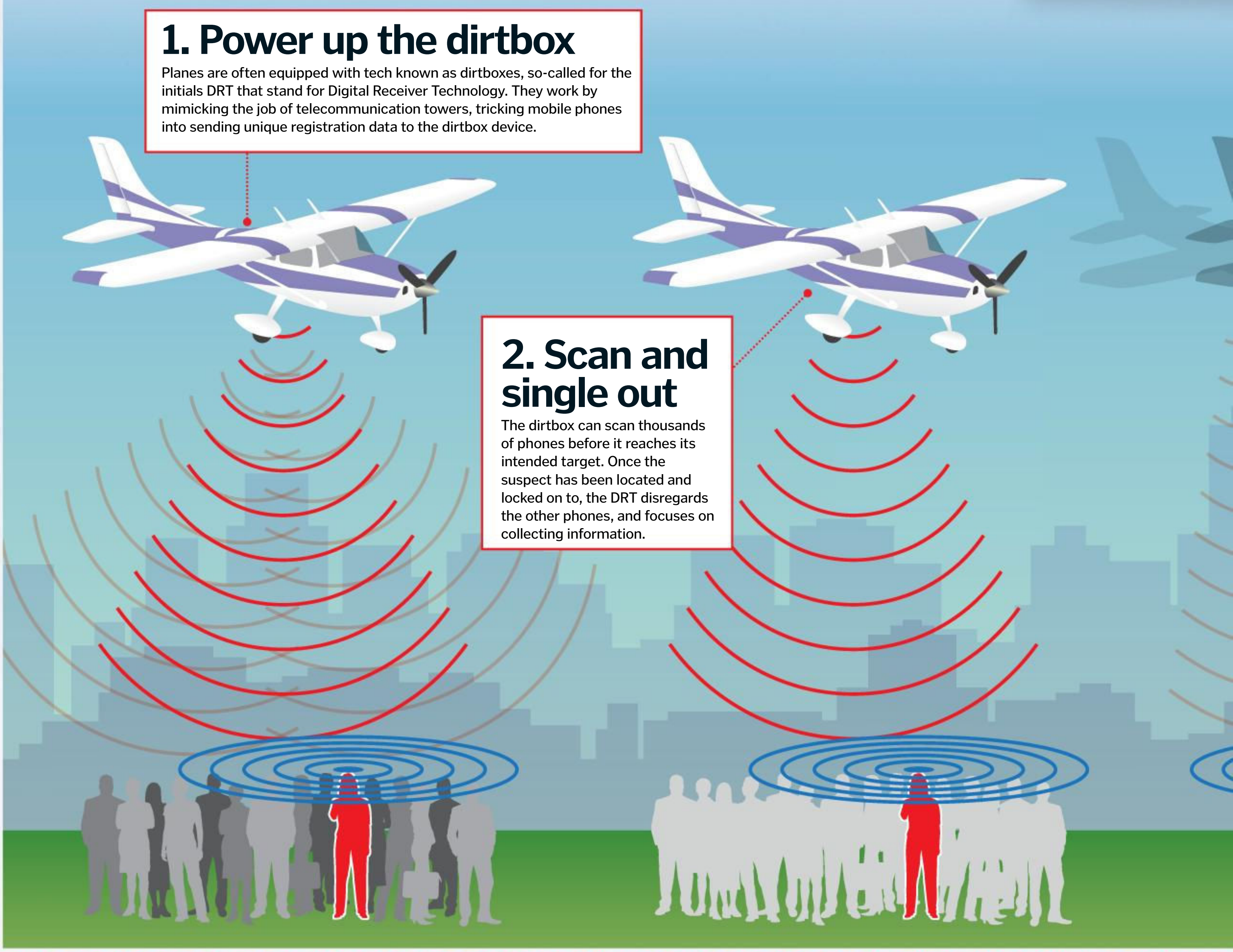
As sound is a big part of sub detection, one of the key ways to avoid being found is to reduce the din. All of the machinery in a submarine will be placed upon acoustic and vibration deadening buffers to minimise the overall noise of the vessel.



Torpedos propel themselves towards underwater targets before detonating

Surveillance strategies

The methods that spy planes use from above to find and track mobile communication signals



imagine a top-level spy plane to look. It has a bulging front profile and a somewhat chunky tail end, but this amazing surveillance drone is able to fly across the world to deliver real-time ISR (Intelligence, Surveillance and Reconnaissance) data to its controllers at US Air Force ground bases.

Unmanned aircraft offer numerous advantages for the advance of spy planes. First of all, engineers do not need to construct a cockpit that safeguards human life. When it comes to creating a monster machine that operates on the very edges of space, this is a money, time and space-saving bonus. The other benefit of using a spy drone instead is that it can keep going for longer than a mission with an onboard pilot. Many drones can also be pre-programmed to carry out assignments even if contact is lost with its base team.

One such spy drone causing ripples in aerial reconnaissance is Northrop Grumman's RQ-180. Not much is known about this robot apart from the fact that it exists, and that the stealth drone is designated for flying in defended airspace for spying on heavily armed rival nations. It's thought that to evade radar detection, this drone may be designed with the 'cranked kite' formation, where the shape is a fusion of the 'kite' and 'flying' wing formations. The chunky and angular shapes are designed to scatter oncoming radar waves, so that they can't be bounced back to their location and the plane can fly undetected.


The Global Hawk surveillance drone has been used in combat in Iraq and Afghanistan

"The dirtbox can scan thousands of phones before it reaches its intended target"

3. Get into position

The plane manoeuvres into the best position to get a clear signal from the mobile phone in question. It can detect signal strength and geographical location of the user as well as obtain identifying information about the phone's owner.

4. Homing in

Using this information from the mobile phone signal, a suspect's location can then be pinpointed to within three metres. The dirtbox can even help to track a person down to a specific room in a building.

The unlikely spy plane

Cessna is a company known for making light aircraft, the type that any pleasure pilot would take out for an afternoon's flight. Yet in 2015 the internet saw an explosion of reports that the FBI had outfitted some of these nondescript civilian airplanes with high-tech surveillance gadgetry.

The Cessna 182 'Skylane' is one such craft, having had the investigative force of the Bureau behind its major upgrades; the thermal imaging and infrared cameras, night vision technology plus mobile phone interceptors are just a few add-ons. These features help the FBI to follow on-going investigations targeting specific individuals, as well as support law enforcement.

These humble planes have also received high-grade makeovers from the US Air Force, who have kitted out a 182 Skylane with modifications to be used in military training exercises. The plane has all the intelligence, surveillance and reconnaissance sensors it needs to be able to mimic that of a Predator Unmanned Aerial Vehicle.

The single-engine Cessna 182 Skylane plane is proving an excellent choice for unobtrusive surveillance

As well as the shape of the aircraft, radar-absorbent materials can also be used to make them less visible. When the waves from the seeking radar hit it, these coatings can deflect the waves and send them in another direction, or in such a manner that the deflected waves cancel out the incoming ones. This renders the craft practically undiscoverable.

Stealth, speed and strength are all very well, but if a spy plane can't carry a decent payload then it's not worth its salt. There are countless


Spy planes are capable of reaching enormous altitudes

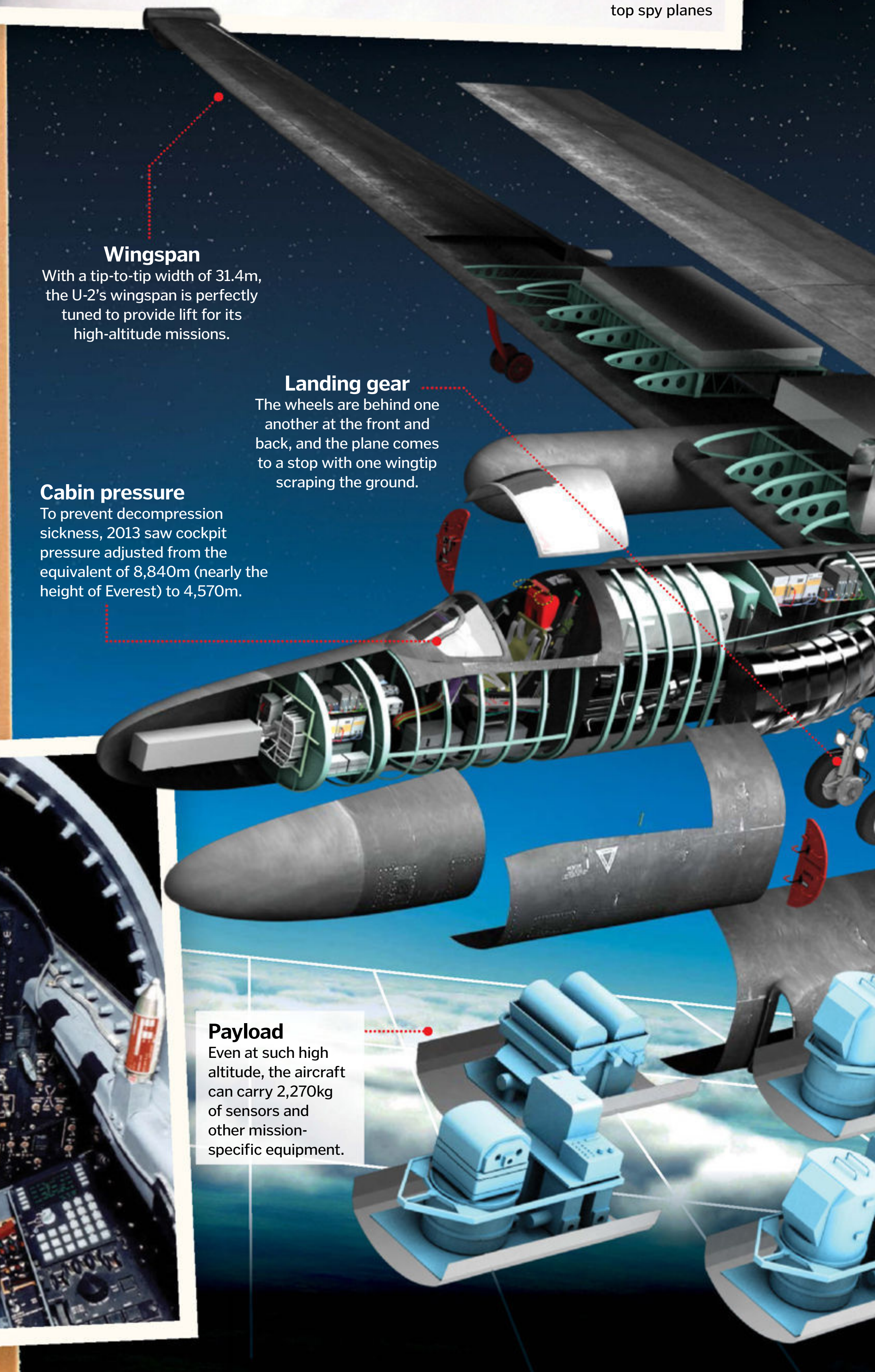
different gadgets and gizmos that can be attached, built in, added or upgraded in order to turn an ordinary military aircraft into a hub of digital sensory perception. Radar and sonar, for example, use radio and sound waves (respectively) that bounce off objects to pinpoint their location.

Reconnaissance aircraft will often carry high-resolution imaging equipment, with top-level zooms and digital video streaming and recording capabilities. Thermal imaging and infrared sensors are other payload regulars, along with a plethora of communications interceptors, acoustic monitoring and many other ways to listen in on the rest of the world. The data is delivered to analysts either onboard or on the ground via high-speed real-time links, so the intelligence gathered can be used advantageously.

It would seem that the future for ISR missions involves plenty of speed, power and altitude with the benefit of automated features. Although there are no plans to retire the old faithfuls like Lockheed's U-2 Dragon Lady just yet, there are also plenty of rumours circulating about plans for faster, meaner, more multifunctional spy planes.

One such concept is the TR-X – another Lockheed invention from their famous Skunk Works spy plane creation station in California. The planning stages are still in their infancy, but Lockheed have stated this spy plane will take the best bits of all the other great spy planes in the skies today and roll them into one mega plane that could be deployed by 2030. You could keep your eyes on the sky, but you would probably never see it coming.


The Lockheed U-2 reconnaissance plane is regarded as one of the world's top spy planes



The Lockheed U-2 cockpit is packed full of high-tech features designed to inform and assist the pilot

Lockheed U-2

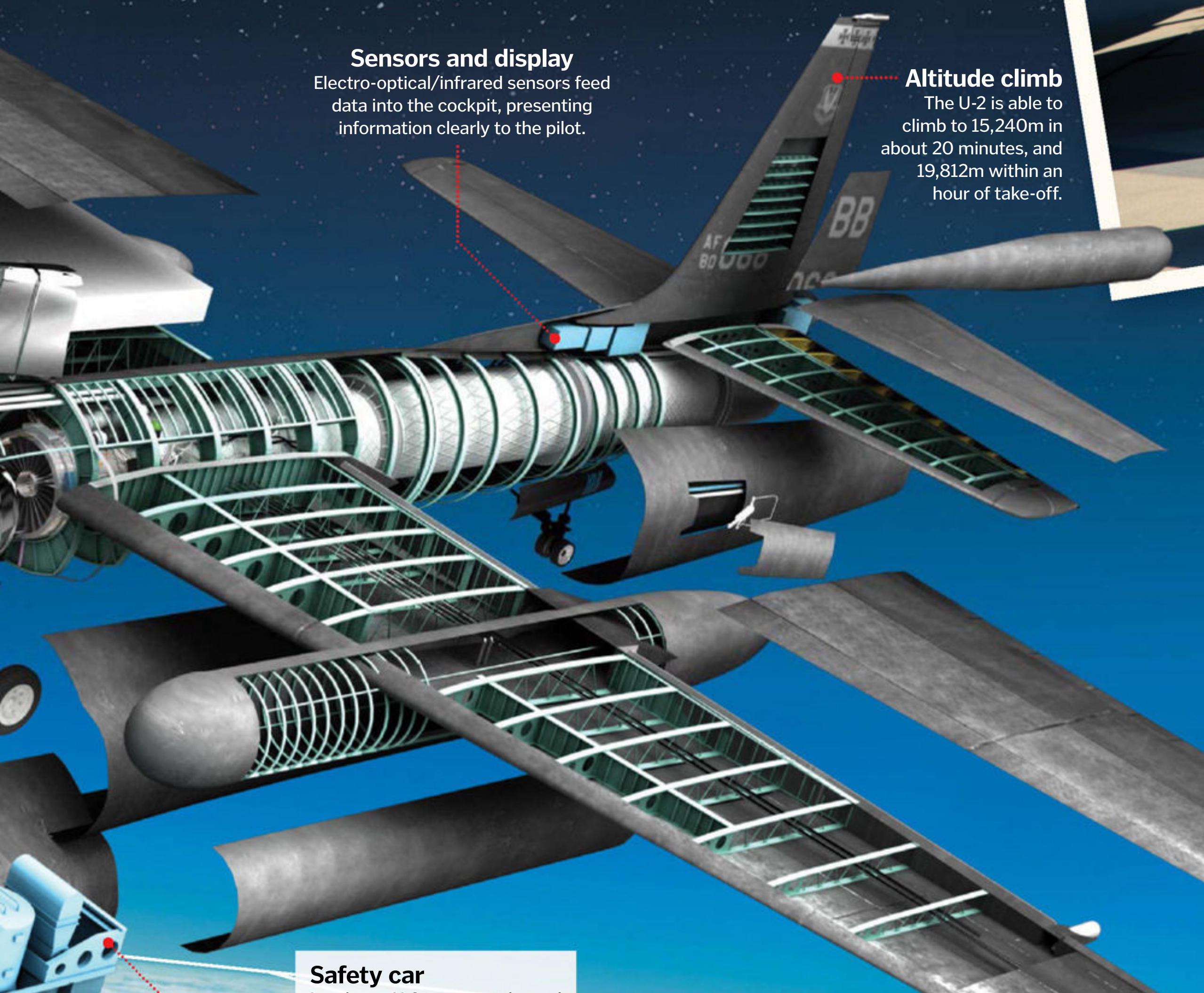
The plane that peeked around the Iron Curtain is still going strong

Named 'Dragon Lady' by the US Air Force, the U-2 was the brainchild of engineer Clarence 'Kelly' Johnson and went from design to test flight in just nine months. The slender body and long wingspan allow it to fly a range of over 4,800 kilometres at an altitude of over 21 kilometres.

The next-gen U-2 family, the U-2S, was built in the 1980s and is expected to be operational beyond 2050. These planes are fitted with state-of-the-art sensor systems that are able to collect data day and night, in all weather. The intelligence is distributed in real time for analysis and exploitation over super-fast digital links.

Today, some of the U-2's work is for NASA, equipped with various sensors to conduct atmospheric tests. U-2s have also patrolled the skies above Iraq and Afghanistan, intercepting insurgent communications and using their incredible imaging sensors to detect small disturbances on the ground, alerting troops to the presence of improvised explosive devices and mines.


U-2 pilots wear pressurised space suits to keep themselves protected when flying at high altitude



Sensors and display
Electro-optical/infrared sensors feed data into the cockpit, presenting information clearly to the pilot.

Altitude climb
The U-2 is able to climb to 15,240m in about 20 minutes, and 19,812m within an hour of take-off.

Safety car
Landing a U-2 is very tricky and requires the help of another pilot giving radio instruction from a safety car.

"The next-gen U-2 family, the U-2S, was built in the 1980s and is expected to be operational beyond 2050"


NASA captures atmospheric data using the U-2

Sea Harrier

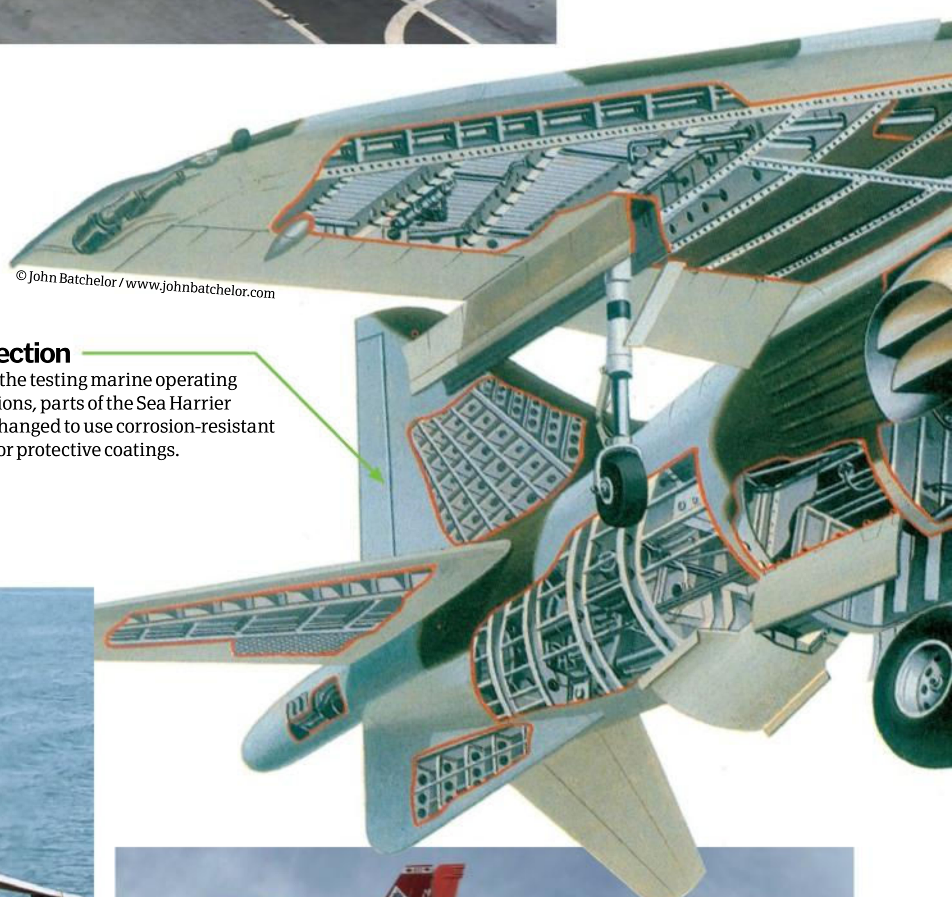
Before being retired in 2006, the Sea Harrier dominated the subsonic jet fighter field, changing the dynamics and operation of the strike fighter role forever

The British Aerospace Sea Harrier was the purpose-built naval variant of the Hawker Siddeley Harrier strike fighter, an aircraft famed for its vertical take-off and landing (VTOL) and short take-off and vertical landing (STOVL) capabilities. It worked by adopting the revolutionary single-engine thrust vectoring technology of the regular harrier (see 'Degrees of power' boxout) and partnering it with a modified fuselage – to allow the installation of the superb Blue Fox radar system – bubble-style canopy (larger, allowing greater visibility) and a significantly improved arms load out.

These factors, partnered with the aircraft carrier's ability to launch the aircraft from its ski-jump, allowed the Sea Harrier to perform to a high standard at sea, carrying more weight, detecting enemies sooner and taking them down quickly and efficiently. This was demonstrated most vividly during the Falklands War of 1982, when 28 Sea Harriers operating off British aircraft carriers shot down 20 Argentine aircraft in air-to-air combat without suffering a single loss. The Sea Harrier squadron achieved this due to their high manoeuvrability and tactics while in dogfights – for example, braking/changing direction fast by vectoring their thrust nozzles while in forward flight – as well as their pilots' superior training and early-warning/detection systems.

Thrust vectoring

To achieve VTOL capabilities, the Sea Harrier's engine thrust was directed through four vectoring nozzles, which could rotate through 98.5 degrees from vertically downwards to horizontal.



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Protection

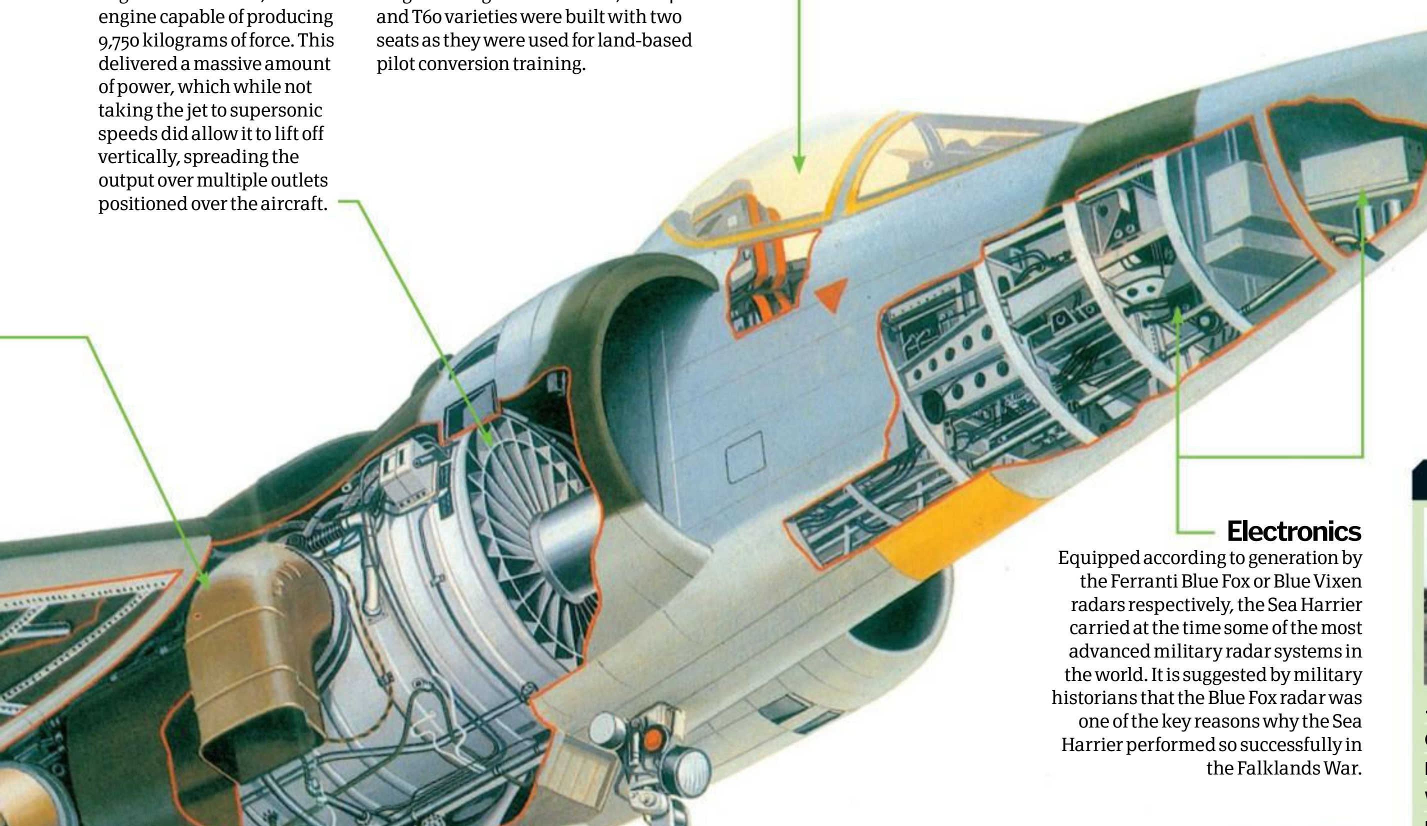
Due to the testing marine operating conditions, parts of the Sea Harrier were changed to use corrosion-resistant alloys or protective coatings.

Second-generation Sea Harriers on board an aircraft carrier in the Persian Gulf

Two Indian Navy Sea Harriers fly alongside a US Navy F/A-18F Super Hornet

Powerplant
The Sea Harrier was fitted with the Rolls-Royce Pegasus 11 turbofan, an engine capable of producing 9,750 kilograms of force. This delivered a massive amount of power, which while not taking the jet to supersonic speeds did allow it to lift off vertically, spreading the output over multiple outlets positioned over the aircraft.

Crew
The first-generation Sea Harrier FRS1 and second-generation FA2 were both single-seat fighters. However, the T4N and T60 varieties were built with two seats as they were used for land-based pilot conversion training.



Electronics
Equipped according to generation by the Ferranti Blue Fox or Blue Vixen radars respectively, the Sea Harrier carried at the time some of the most advanced military radar systems in the world. It is suggested by military historians that the Blue Fox radar was one of the key reasons why the Sea Harrier performed so successfully in the Falklands War.


Some Harriers were fitted with the AIM-120 AMRAAM missile

Armament
As a strike fighter the Sea Harrier was equipped with a broad arsenal, ranging from conventional, unguided iron bombs – including WE.177 nuclear options – to rockets and laser-guided missiles such as the AIM-9 Sidewinder. The second generation FA2 was famously equipped with deadly AIM-120 AMRAAM air-to-air, fire and forget missiles.

The statistics...

Sea Harrier FA2

Crew: 1
Length: 14.2m
Wingspan: 7.6m
Height: 3.71m
Max take-off weight: 11,900kg
Powerplant: 1 x Rolls-Royce Pegasus turbofan (21,500lbf)
Max speed: 735mph
Combat radius: 1,000km
Max range: 3,600km
Max service ceiling: 16,000m
Guns: 2 x 30mm ADEN cannon pods (100 rounds per cannon)
Rockets: 72 SNEB 68mm rockets
Missiles: AIM-9 Sidewinder, AIM-120 AMRAAM, R550 Magic, ALARM anti-radiation missile, Martel missile, Sea Eagle anti-ship missile
Cost: $18 million

Degrees of power

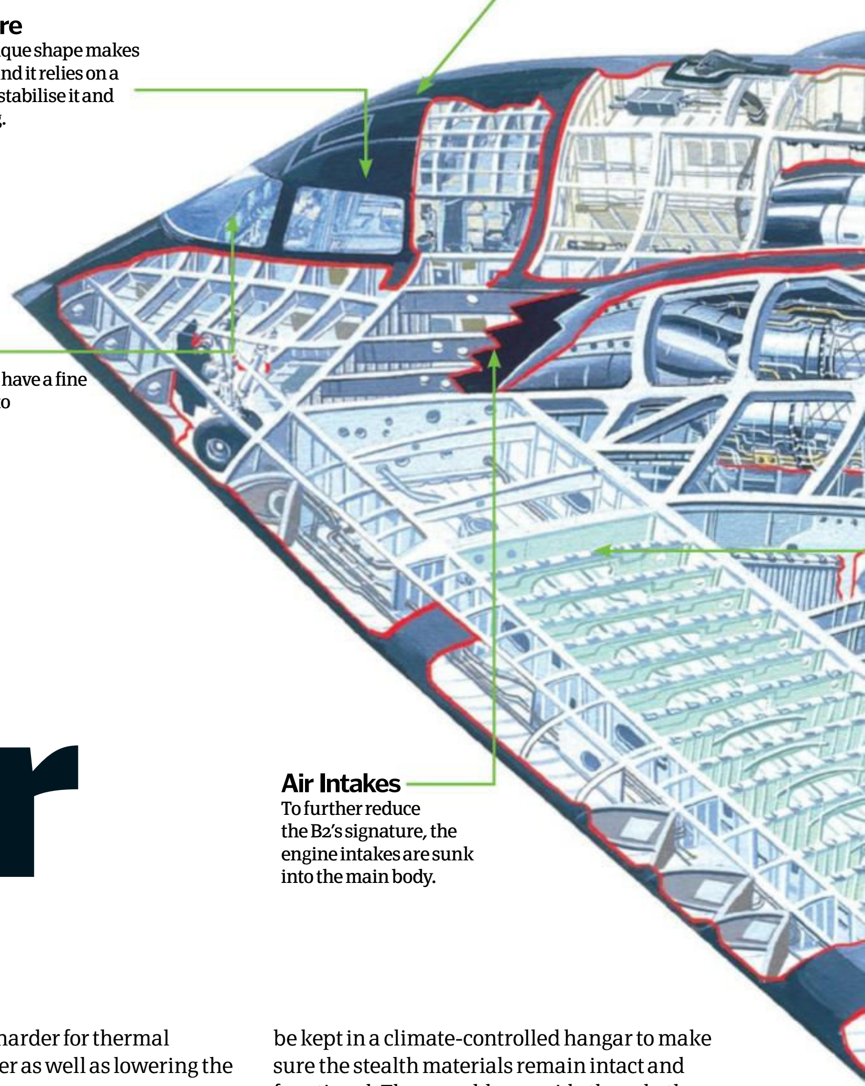
Giving the Sea Harrier lift off

The real showpiece and reason for the lengthy success of the Sea Harrier was its utilisation of the Harrier's revolutionary Pegasus engine partnered with thrust vectoring nozzles. These nozzles could be rotated by the pilot through a 98.5 degree arc, from the conventional aft (horizontal) positioning as standard on aircraft, to straight down, allowing it to take off and land vertically as well as hover, to forward, allowing the Harrier to drift backwards. All nozzles were moved by a series of shafts and chain drives, which insured that they operated in unison (crucial for maintaining stability) and the angle and thrust was determined in-cockpit by the pilot.

This flexibility of control and placement meant that the Sea Harrier was highly manoeuvrable while in the air and could be landed and launched from almost anywhere.

The Sea Harrier's vectoring nozzle in aft position

You may not see the plane, but you'll see the bombs



Stealth Bomber

The B-2 is extraordinary, both in terms of appearance and design

The 'flying wing' shaped Stealth Bomber is a unique aircraft that was designed specially to make it as invisible as possible. Its shape means there are few leading edges for radar to reflect from, reducing its signature. This is further enhanced by the composite materials from which the aircraft is constructed and the coatings on its surface. These are so successful that despite having a 172-foot wingspan, the B-2's radar signature is an astounding 0.1m².

The B-2's stealth capabilities, and aerodynamic shape, are further enhanced by the fact its engines are buried inside the wing. This means the induction fans at the front of the engines are concealed while the engine exhaust is minimised. As a result, the B-2's thermal signature is kept to the bare minimum, making it harder for thermal sensors to detect the bomber as well as lowering the aircraft's acoustic footprint.

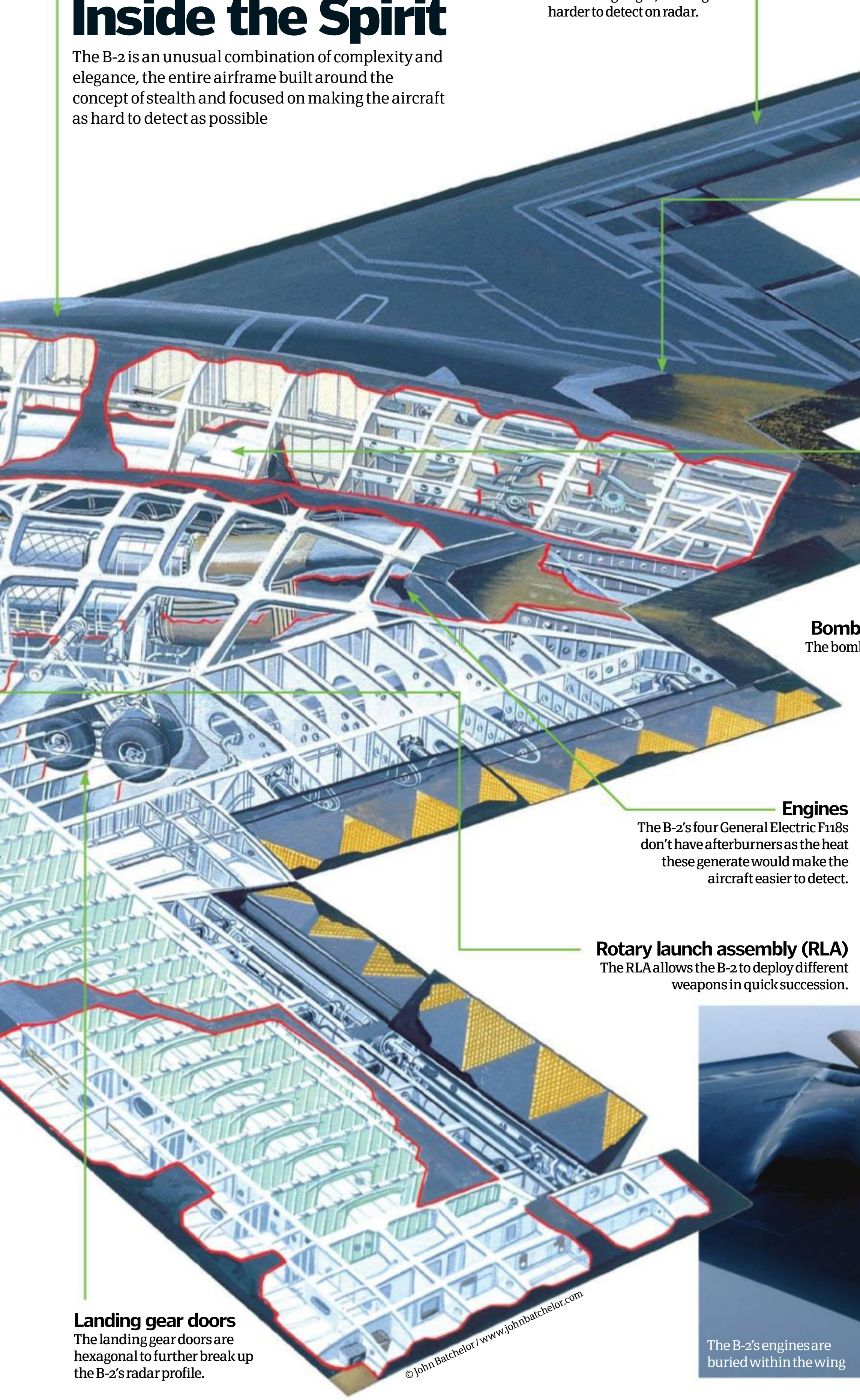
The design also means the B-2 is both highly aerodynamic and fuel efficient. The B-2's maximum range is 6,000 nautical miles and as a result the aircraft has often been used for long-range missions, some lasting 30 hours and in one case, 50. The B-2 is so highly automated that it's possible for a single crew member to fly while the other sleeps, uses the lavatory or prepares a hot meal and this combination of range and versatility has meant the aircraft has been used to research sleep cycles to improve crew performance on long-range missions.

Despite this, the aircraft's success comes with a hefty price tag. Each B-2 costs $737 million and must be kept in a climate-controlled hangar to make sure the stealth materials remain intact and functional. These problems aside though, the Spirit is truly an astonishing aircraft, even if, chances are, you won't see one unless the pilots want you to...

Not one you're likely to find in your I-Spy book...

Ghost works: Inside the Spirit

The B-2 is an unusual combination of complexity and elegance, the entire airframe built around the concept of stealth and focused on making the aircraft as hard to detect as possible



Flying wing
The B-2's shape means it has very few leading edges, making it harder to detect on radar.

Carbon-reinforced plastic
Special heat-resistant material near the exhausts mean the airframe absorbs very little heat.

Bomb rack assembly (BRA)
The bomb rack assembly can hold up to 80 500lb bombs.

Engines
The B-2's four General Electric F118s don't have afterburners as the heat these generate would make the aircraft easier to detect.

Rotary launch assembly (RLA)
The RLA allows the B-2 to deploy different weapons in quick succession.

Landing gear doors
The landing gear doors are hexagonal to further break up the B-2's radar profile.

The statistics...

B-2 Spirit

Manufacturer: Northrop Grumman

Year deployed: 1993

Dimensions: Length: 69ft, wingspan: 172ft, height: 17ft

Weight empty / max: 158,000lb / 336,500lb

Unit cost: $737,000,000

Max speed: Mach 0.95 (604mph)

Propulsion: The B-2 has general Electric F118-GE-100 non-afterburning turbofans

Ceiling: 50,000ft

Armament description: The B-2 has two internal bays capable of holding 50,000lb of ordnance. Common payloads often include:
- 80 × 500lb class bombs (Mk-82) mounted on the bomb rack assembly or BRA
- 36 × 750lb CBU class bombs on BRA
- 16 × 2,000lb class weapons (Mk-84, JDAM-84, JDAM-102) mounted on the rotary launcher assembly RLA
- 16 × B61 or B83 nuclear weapons on the RLA

Landings are fine, if the tower spots you coming…

The B-2's engines are buried within the wing

Mikoyan MiG-29

Russia's primary fighter jet combines a host of advanced tech to create an agile and deadly aircraft

Often overlooked in the west due to its Soviet Union origins in the Eighties, the Mikoyan MiG-29 is actually one of the world's most prolific fighter jets, with over 1,600 units in operation around the globe. For a little perspective, there are only just over 300 Eurofighter Typhoons currently in operation across the planet, a number that is unlikely to ever exceed the 500 mark.

So why is this Russian plane so successful? For starters, it's great value for money – just shy of £18 million ($29 million), compared to the £64.8 million ($104.6 million) Typhoon.

The MiG-29 is a fourth-generation fighter jet designed for an air supremacy role, which involves infiltrating and seizing enemy airspace through force. It comes in a wide range of variants, with both legacy and current production models (such as the MiG-29K and MiG-29M) in operation, and has seen significant combat throughout its 19-year service, including deployment in the Persian Gulf War.

The aircraft is built around an aluminium airframe, which is bolstered with advanced composite materials. This airframe is designed for up to 9g manoeuvres, making the jet insanely agile and quite easy to fly for skilled pilots – hence why it's often used at air shows.

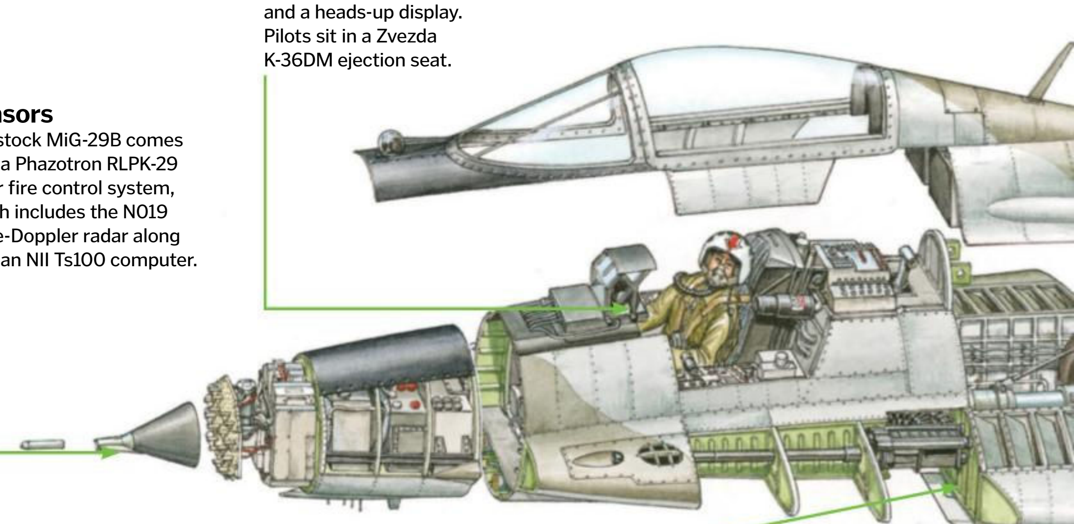
Surrounding the airframe lies an elegantly sculpted titanium/aluminium alloy fuselage that tapers in from a wide rear to a raised, 'swan neck' cockpit and elongated nose cone. From the fuselage extends the aeroplane's mid-mounted swept wings, each of which is installed with leading-edge root extensions.

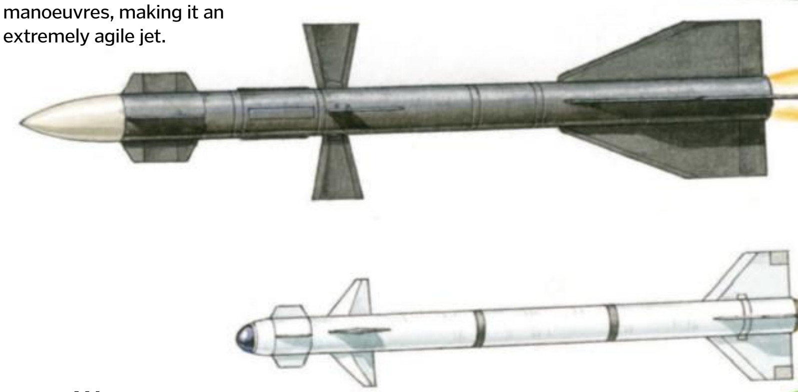
The MiG-29 is powered by two widely spaced Klimov RD-33 afterburning turbofans that, besides granting a top speed of 2,400 kilometres (1,490 miles) per hour, also help reduce effective wing loading. This is thanks to their wide spacing, with the area between them generating extra lift. The engines are fed by an internal fuel system that parses its total reserves down into a series of sub-tanks.

The MiG-29 comes packing a vast arsenal too. Each jet is fitted with seven hardpoints capable of carrying a wide array of missiles and bombs, or external fuel tanks for longer missions.

Anatomy of a MiG-29B

The essential hardware of this Russian air superiority fighter revealed





Cockpit
The MiG-29B's cockpit has a bubble canopy and comes equipped with a conventional centre stick, left-hand throttle controls and a heads-up display. Pilots sit in a Zvezda K-36DM ejection seat.

Sensors
The stock MiG-29B comes with a Phazotron RLPK-29 radar fire control system, which includes the N019 pulse-Doppler radar along with an NII Ts100 computer.

Airframe
The MiG-29B's airframe is made primarily from aluminium and composite materials. The airframe is stressed for up to 9g manoeuvres, making it an extremely agile jet.

Weapons
The MiG-29B comes with seven hardpoints, each capable of carrying a selection of arms (such as R-73 air-to-air missiles) and bombs. In addition, it carries a single GSh-30-1 30mm (1.2in) cannon.

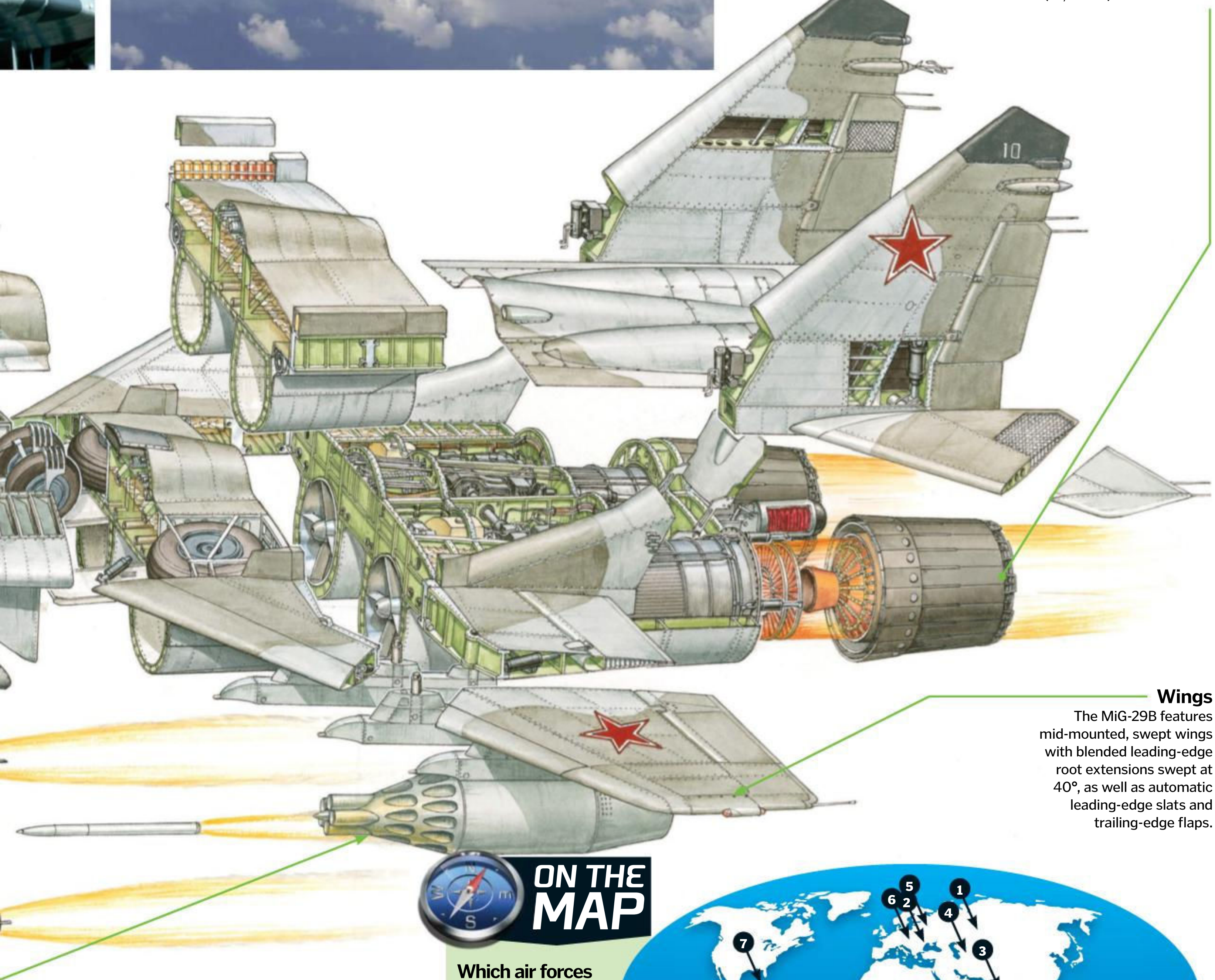
The statistics...

Mikoyan MiG-29

Crew: 1
Length: 17.4m (57ft)
Wingspan: 11.4m (37.4ft)
Height: 4.7m (15.4ft)
Powerplant: 2 x Klimov RD-33 afterburning turbofans
Max speed: Mach 2.25 (2,400km/h; 1,490mph)
Max range: 1,430km (888mi)
Max altitude: 18,013m (59,100ft)
Hardpoints: 7
Max payload: 3,500kg (7,720lb)

Powerplant

The fighter jet comes installed with two Klimov RD-33 afterburning turbofans, which are widely spaced to reduce wing loading and improve manoeuvrability. They each deliver 8,290kgf (18,277lbf) on afterburner.



Wings

The MiG-29B features mid-mounted, swept wings with blended leading-edge root extensions swept at 40°, as well as automatic leading-edge slats and trailing-edge flaps.

ON THE MAP

Which air forces fly MiG-29s?

1 Russia: 291
2 Ukraine: 80
3 India: 67
4 Uzbekistan: 60
5 Belarus: 41
6 Poland: 36
7 Cuba: 4

F-14 Tomcat

One of the most iconic fighter jets ever built, the F-14 Tomcat dominated modern warfare for decades, delivering great performance across the wide spectrum of aerial engagement

Designed to protect the US Navy's aircraft-carrier operations at long ranges against Soviet aircraft and missiles, the Grumman Corporation-built F-14 Tomcat has been entrenched in military history and public consciousness for decades. Made famous by its numerous high-profile operations – including missions in the Vietnam, Gulf and Iraq wars – and extensive usage in the Eighties classic film *Top Gun*, the F-14 has been synonymous with prestige, advanced technology and dynamic, aggressive flight performance.

This reputation emanated from its next-generation, multi-use design, which allowed it to be utilised as both a long-range naval interceptor and air superiority fighter, making it capable of fighting in any aerial engagement. Key to this was the F-14's variable geometry wings, a sweeping system that could modify the wing position between 20 and 68 degrees depending on the nature of the operation. At high speeds, which the F-14 was capable of with great ease, the wings would be swept back, while when undertaking long-haul patrol missions at lower speeds, the wings could fully extend out, maximising its lift-to-drag ratio and improving fuel efficiency.

While in flight, its power was supplied by two Pratt & Whitney TF30 turbofans, jet engines each capable of delivering a massive 27,800 pounds of thrust with afterburners engaged. This gave the F-14 a top speed of 1,544mph (2,484kph), over twice the speed of sound, as well as a rapid rate of climb of 229 metres (751ft) a second and overall thrust-to-weight ratio of 0.91. However, due to the F-14's design brief as a multi-role aircraft, the TF30s could not only provide huge thrust but were also designed to be fuel-efficient when cruising at low speeds to maximise fuel economy.

The Tomcat was also notable for its adoption of numerous advanced electronic systems to aid flight and navigation, as demonstrated in its Central Air Data Computer (CADC) and Hughes AWG-9 X-band digital radar. The former utilised a MOS-based LSI chipset, the MP944 – one of the first microprocessor designs – and could control the primary flight system, wing sweep and flaps automatically, while the latter provided next-generation search and tracking modes that could monitor and lock onto targets hundreds of miles away.

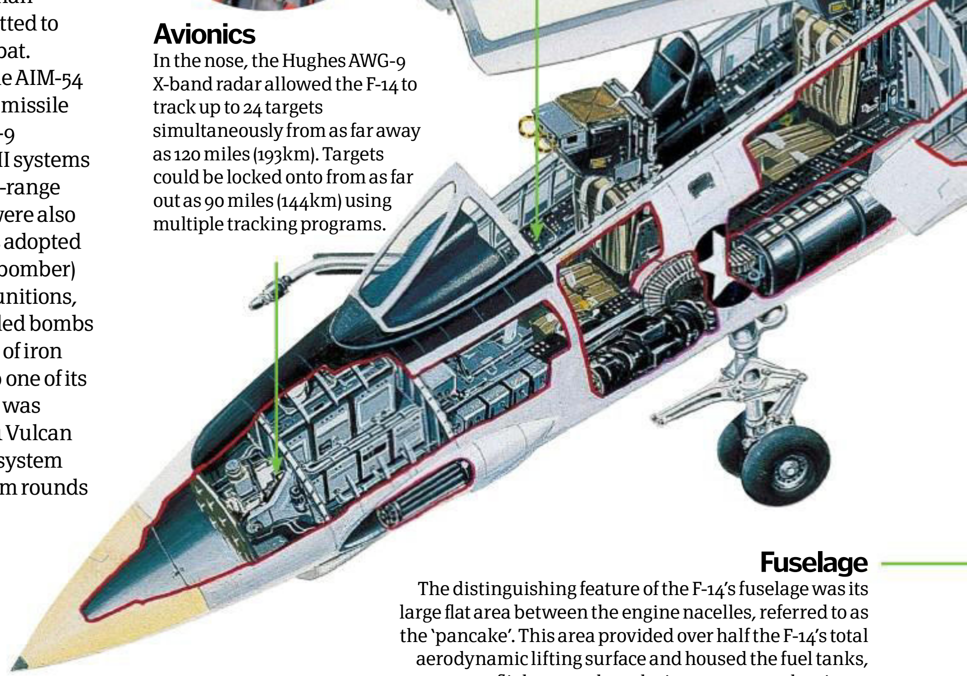
Once enemy targets had been discovered, the F-14 was more than capable of taking them down, fitted to counter every aspect of air combat. Missiles included the formidable AIM-54 Phoenix, a long-range air-to-air missile system, as well as both the AIM-9 Sidewinder and AIM-Sparrow III systems to deal with short- and medium-range targets. Air-to-ground options were also not in short supply (the F-14 was adopted late on in its service period as a bomber) with JDAM precision-guided munitions, the Paveway series of laser-guided bombs and the MK 80 and MK 20 series of iron bombs capable of being fitted to one of its ten hardpoints. Finally, the F-14 was installed with the ferocious M61 Vulcan six-barrelled gatling cannon, a system capable of firing over 6,000 20mm rounds every 60 seconds.

Wings could be fully extended for long-haul missions

The statistics…

F-14 Tomcat

Crew: Two
Length: 19.1m (62.6ft)
Wingspan: 19.55m (64ft)
Height: 4.88m (15.7ft)
Weight: 19.83m (65ft)
Powerplant: Two x General Electric F110-GE-400 afterburning turbofans
Max thrust: 13,810lbf
Max speed: Mach 2.34 (1,544mph/2,484kph)
Combat radius: 575mi/ 925km
Max altitude: 15,200m (49,868ft)
Armament: One x 20mm M61 Vulcan gatling cannon
Hardpoints: 10 (six under fuselage, two under nacelles, two on wing gloves)
Missiles: AIM-54 Phoenix, AIM-7 Sparrow, AIM-9 Sidewinder
Bombs: JDAM, Pavewave, Mk 80, Mk 20 Rockeye II
Cost: $38 million

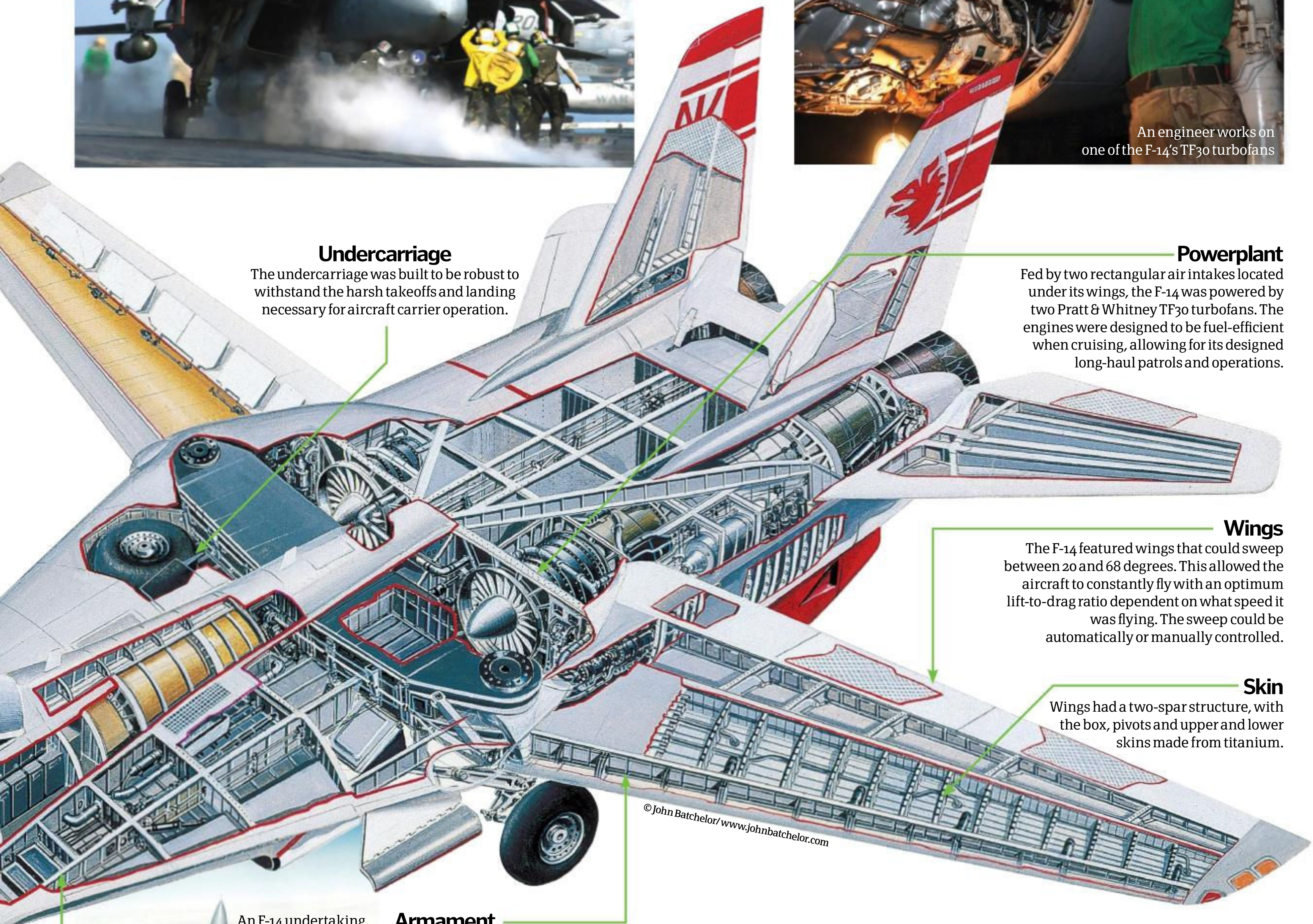


Avionics
In the nose, the Hughes AWG-9 X-band radar allowed the F-14 to track up to 24 targets simultaneously from as far away as 120 miles (193km). Targets could be locked onto from as far out as 90 miles (144km) using multiple tracking programs.

Fuselage
The distinguishing feature of the F-14's fuselage was its large flat area between the engine nacelles, referred to as the 'pancake'. This area provided over half the F-14's total aerodynamic lifting surface and housed the fuel tanks, flight controls and wing-sweep mechanisms.

"Umm guys, I'm trying to take off here…"

An engineer works on one of the F-14's TF30 turbofans



Undercarriage

The undercarriage was built to be robust to withstand the harsh takeoffs and landing necessary for aircraft carrier operation.

Powerplant

Fed by two rectangular air intakes located under its wings, the F-14 was powered by two Pratt & Whitney TF30 turbofans. The engines were designed to be fuel-efficient when cruising, allowing for its designed long-haul patrols and operations.

Wings

The F-14 featured wings that could sweep between 20 and 68 degrees. This allowed the aircraft to constantly fly with an optimum lift-to-drag ratio dependent on what speed it was flying. The sweep could be automatically or manually controlled.

Skin

Wings had a two-spar structure, with the box, pivots and upper and lower skins made from titanium.

Armament

The F-14's standard layout included a single long-range air-to-air AIM-54 Phoenix, two short-range air-to-air AIM-9 Sidewinders, two air-to-air AIM-7 Sparrow IIIs and an M61 Vulcan autocannon capable of firing 6,000 rounds per minute.

An F-14 undertaking a vertical climb

The insane M61 Vulcan autocannon

An F-14 flying over Iraq during the Gulf war

AH-64D Apach

The latest iteration of the combat-tested Apache gunship, the AH-64D Longbow is a powerhouse of performance, bringing massive damage and flexibility to the theatre of war

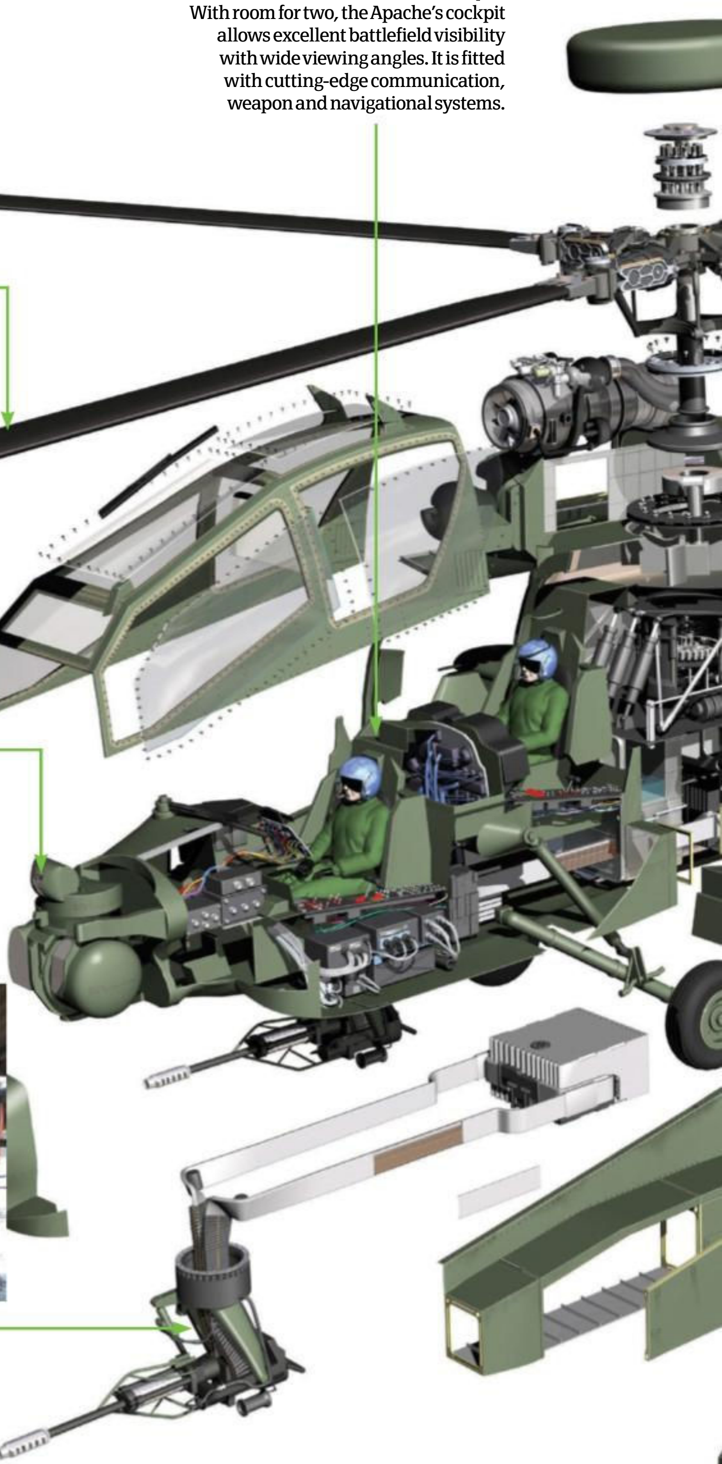
Emerging as the next generation of multi-mission attack helicopter, the AH-64D Apache Longbow is changing the face of warfare today. Recently in operation in Iraq and Afghanistan, and used by armed forces all over the world, its military performance is well-recognised and has proved itself both combat-ready and reliable over the last 13 years of service.

The AH-64D Apache Longbow is the latest iteration of the Apache class of gunship as produced by Boeing. Differentiating it from earlier models, the AH-64D Longbow is now fitted with a fire-control radar above its four-blade composite main rotor. This allows it longer-range weapons accuracy, cloaked object detection (both moving and stationary), classification and threat-prioritisation of up to 128 targets in less than 60 seconds and greater situational awareness, real-time management of the combat arena and digital transmission of target locations.

Married to these advanced systems is an armament to make the most armoured target rethink their strategy. Topping this list of destruction is the Apache's Hellfire missiles, which are dedicated laser-guided anti-armour missiles that make short work of tanks, bunkers and artillery.

The Longbow is also fitted with a brace of 70mm rockets, which can be fired off in quick succession and provide awesome power and flexibility when up against numerous targets. Lastly, mounted on its underside is the AH-64D's 30mm M230 chain gun. Holding 1,200 30mm high-incendiary rounds, and controlled remotely by the pilot through his helmet – allowing hands-free targeting and tracking – the M230 chain gun is capable of laying down a phenomenal amount of damage and is ideal for clearing enemy soldiers on the ground.

Since 2008, the AH-64D has also been upgraded to include increased digitisation, a joint tactical radio system, enhanced engines and drive systems, capability to control UAVs (unmanned aerial vehicles) – which have been used extensively in the Iraq and Afghanistan wars – and improved landing gear. Currently, the Apache AH-64D Longbow is operated by America, Egypt, Greece, Israel, Japan, Kuwait, Netherlands, China, Singapore and the United Arab Emirates, with many other countries operating earlier variants.



5. Cockpit
With room for two, the Apache's cockpit allows excellent battlefield visibility with wide viewing angles. It is fitted with cutting-edge communication, weapon and navigational systems.

6. Composite rotor blades
The AH-64D Longbow is fitted with a new composite four-blade main rotor, allowing for increased payload, climb rate and cruise speed over earlier variants.

8. Radome
Through the systems within, this provides the Longbow with combat information on its surroundings and enemies, such as target azimuth, elevation, range and velocity. This allows it to quickly and efficiently calculate a firing solution to best hit its targets.

"Say hello to my little friend"

2. 30mm automatic cannon
Firing large, highly incendiary rounds (the Apache carries 1,200 units), the 30mm automatic cannon is a multi-purpose chain gun capable of ripping through man and machine with ease.

ne Longbow

1. T700-GE-701C engines
Produced by General Electric, the T700 turboshaft engines allow the AH-64D Longbow a high vertical rate of climb (2,175fpm) and max cruise speed (284kph).

7. Fuselage
Designed for lightness, manoeuvrability and stealth, the fuselage is distinctively styled and painted in camouflaged colours to match its operating environment.

3. Laser-guided Hellfire missiles
Multi-platform and multi-target, these laser-guided modular missiles are excellent at taking down enemy armour and structures.

4. 70mm explosive rockets
Fast firing 2.75-inch rockets allow the Apache to support ground troops in any assault, destroying enemy soldiers, strongholds and vehicles.

The statistics...

AH-64D Apache Longbow

Length: 58.17ft (17.73m)
Height: 15.24ft (4.64m)
Engine: Twin turboshaft T700-GE-701C
Max speed: 284kph
Cost: $15.4 million
Number produced: 1,174 (Feb 2010)
Armament: Hellfire missiles, 70mm rockets, 30mm M230 chain gun


An Apache AH-64 fires flares in the early morning


A vehicle of modern warfare

Sikorsky MH-60 Black Hawk

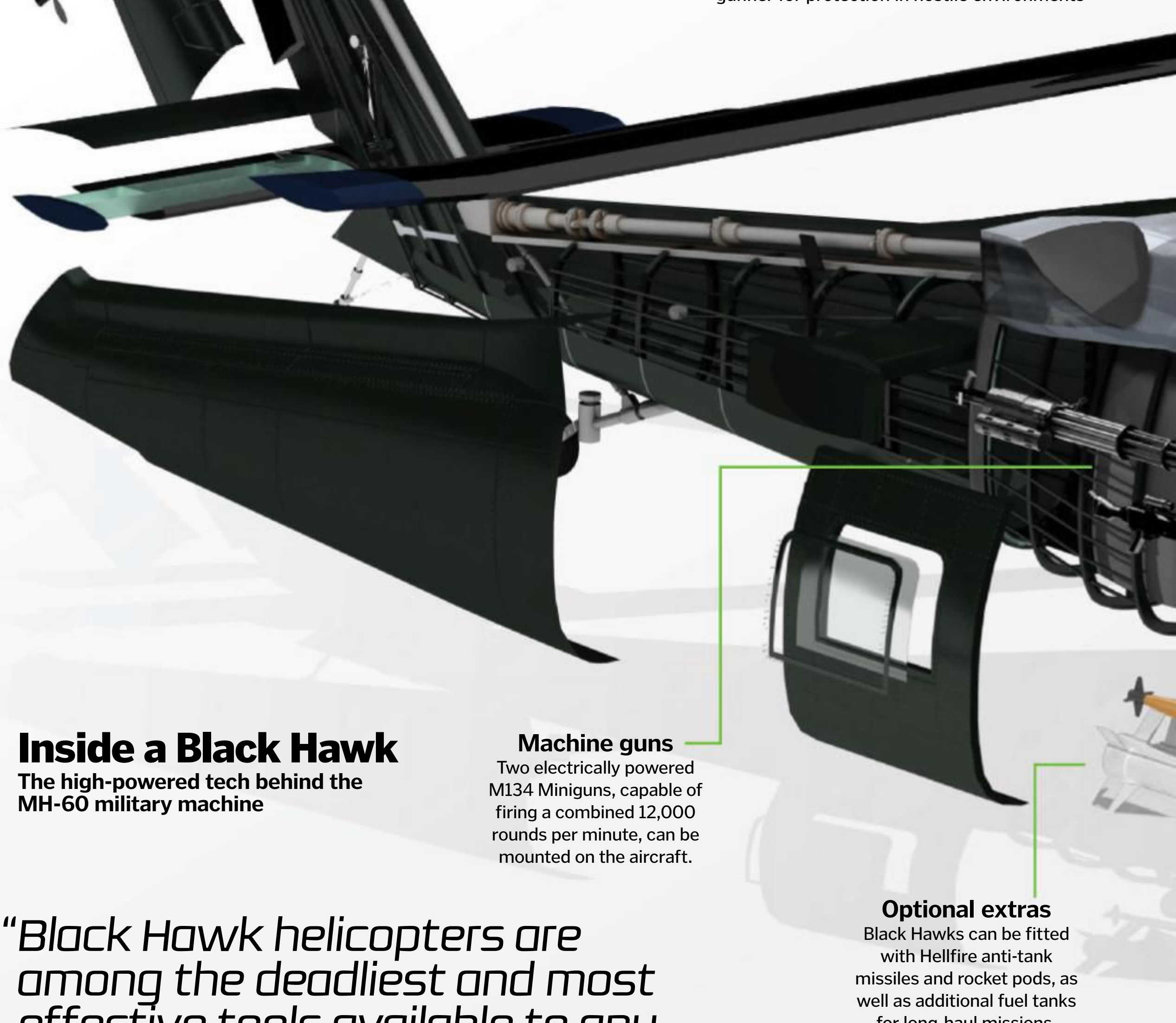
Designed for special operations in hostile environments, this was a new kind of war machine, built for a new kind of battlefield

From the chaotic skies over Somalia during the Battle of Mogadishu in 1993, to the covert operation to kill Osama Bin Laden in 2011, Black Hawk helicopters are among the deadliest, most effective tools available to any modern military. After its experiences in the Vietnam War in the 1960s and 70s, the US military knew just how essential it was to have tough, multi-role helicopters available. Not only were these aircraft useful for rapidly transporting combat personnel to and from battlefields, they could even remain on the front line to provide direct support. However, the existing Huey helicopters were out of date.

Two US companies, Boeing Vertol and Sikorsky, went head-to-head with their rival designs for the new combat helicopter, with the latter finally winning the contract with its S-70 prototype. Since the model first took to the skies in 1974, a huge number of variants have gone into production, each with its own specific role to play in a combat zone. For instance, the secretive 'MH-X' version – used during the mission to kill Al-Qaeda's chief – was rumoured to be equipped with stealth technology, making it almost undetectable to radar.

The MH-60 variant seen here was developed from the standard UH-60 Black Hawk for use during special operations. The machine's effective range was greatly increased with the addition of a more efficient fuel tank, the installation of systems for aerial refuelling, and the improvement of the craft's overall survivability. It was during a special operation that these assets would be put to the ultimate test, an incident known as Black Hawk Down.

The Black Hawk is capable of carrying a range of weaponry, and will often house a door gunner for protection in hostile environments



Inside a Black Hawk

The high-powered tech behind the MH-60 military machine

"Black Hawk helicopters are among the deadliest and most effective tools available to any modern military"

The Battle of Mogadishu

On 3 October 1993, American Rangers flew into Mogadishu, the capital of Somalia, to capture a wanted terrorist leader. They swooped down on the target's base in a convoy of helicopters, with MH-60 Black Hawks hovering overhead to provide support. However, when two of these aircraft came under fire, they crash-landed into the maze of streets and alleyways below. What was supposed to be a smooth operation soon turned into chaos as soldiers battled through the streets to reach the downed aircraft and their stricken crew. The ensuing battle is now most famously known as Black Hawk Down, due to the 1999 book of the same name, which was adapted into the 2001 Oscar-winning film.

A Black Hawk flies over Mogadishu during Operation Restore Hope, a year before the Battle of Mogadishu

The use of night-vision (infrared) technology enables pilots to safely conduct special operations in total darkness

Twin engines
Two General Electric engines pack a combined 3,988 shaft horsepower, enabling the aircraft to reach a top speed of 280km/h.

Safety features
The fuel tank, landing gear and body frame are all reinforced to protect the crew in the event of a crash. Even the pilots' seats are designed to absorb and nullify any critical impact.

Radar
As well as GPS capability, the MH-60 is fitted with multi-mode radar capable of tracking the terrain below, even in poor weather conditions.

Passengers
Up to 18 personnel can be transported in the rear of the aircraft, which has an operational range of over 2,200km.

Night vision
A forward looking infra-red (FLIR) video camera pod captures the surrounding environment and relays it to the pilot, enabling safe flight in total darkness.

100 YEARS OF WARFARE

TANKS

THE EVOLUTION OF ARMOURED BATTLE, FROM WWI TO MODERN MECHANISED MARVELS

Ancient Greek hoplites joined their shields and advanced in unison. Hannibal's Carthaginians mounted war elephants. The visionary Leonardo da Vinci rendered an image of an armoured fighting vehicle in 1487. While the concept of the tank - an armoured unit that could dominate the battlefield - has existed for almost as long as mankind has waged war, it became workable and developed to devastating capability 100 years ago.

Since the creaky bathtubs of World War I, the tank has existed to provide an operational edge during combat. Its varied roles range from the hammer blow of the mailed fist to break through enemy lines, to the rapid exploitation of the breach and the destruction of other vehicles and fortifications, as well as reconnaissance and fire support as mobile artillery.

To successfully complete the assigned mission, tanks require three key design elements: firepower, mobility and protection. Concentrated firepower punches a hole through enemy lines, while being able to tackle any type of terrain at speed enables them to travel over enemy trenches, and heavy armour shields the crew that supplies the expertise, efficiency, and courage to go in harm's way.

When the tank entered combat for the first time, hopes were high that the horrific stalemate of trench warfare would be broken. While the tank matured as an armament system, it became a weapon of dominance and decision. Today, the tank is perceived both as a potential war winner and a costly machine that may be past its prime. Regardless, the technological advancements and its impact on warfare are nothing short of astonishing.

Without question, the mere existence of the tank continues to influence any decision to wage war and any effective defence against an attacker on land. The tank, therefore, remains a prime shaper of military strategy and will continue to be into the foreseeable future.

Tanks through time

Over decades of warfare, technology has shaped tanks into weapons of awesome power

Mark V (Male)
Country of origin: United Kingdom
First produced: 1917
Still in service? No

Char B1 bis
Country of origin: France
First produced: 1937
Still in service? No

Centurion
Country of origin: United Kingdom
First produced: 1945
Still in service?: No

M60
Country of origin: United States
First produced: 1959
Still in service? Yes

PT-76
Country of origin: Soviet Union
First produced: 1950
Still in service? Yes

T-54
Country of origin: Soviet Union
First produced: 1948
Still in service? Yes

T-72
Country of origin: Soviet Union
First produced: 1971
Still in service? Yes

Leopard 2
Country of origin: Germany
First produced: 1979
Still in service? Yes

M1A1 Abrams
Country of origin: United States
First produced: 1979
Still in service? Yes

Challenger 2
Country of origin: United Kingdom
First produced: 1993
Still in service? Yes

Arjun
Country of origin: India
First produced: 2004
Still in service? Yes

K2 Black Panther
Country of origin: South Korea
First produced: 2013
Still in service? Yes

T-90
Country of origin: Russia
First produced: 1993
Still in service? Yes

The T-72 tank has been exported to over 30 countries

Challenger 2 is equipped with a highly accurate fire control system

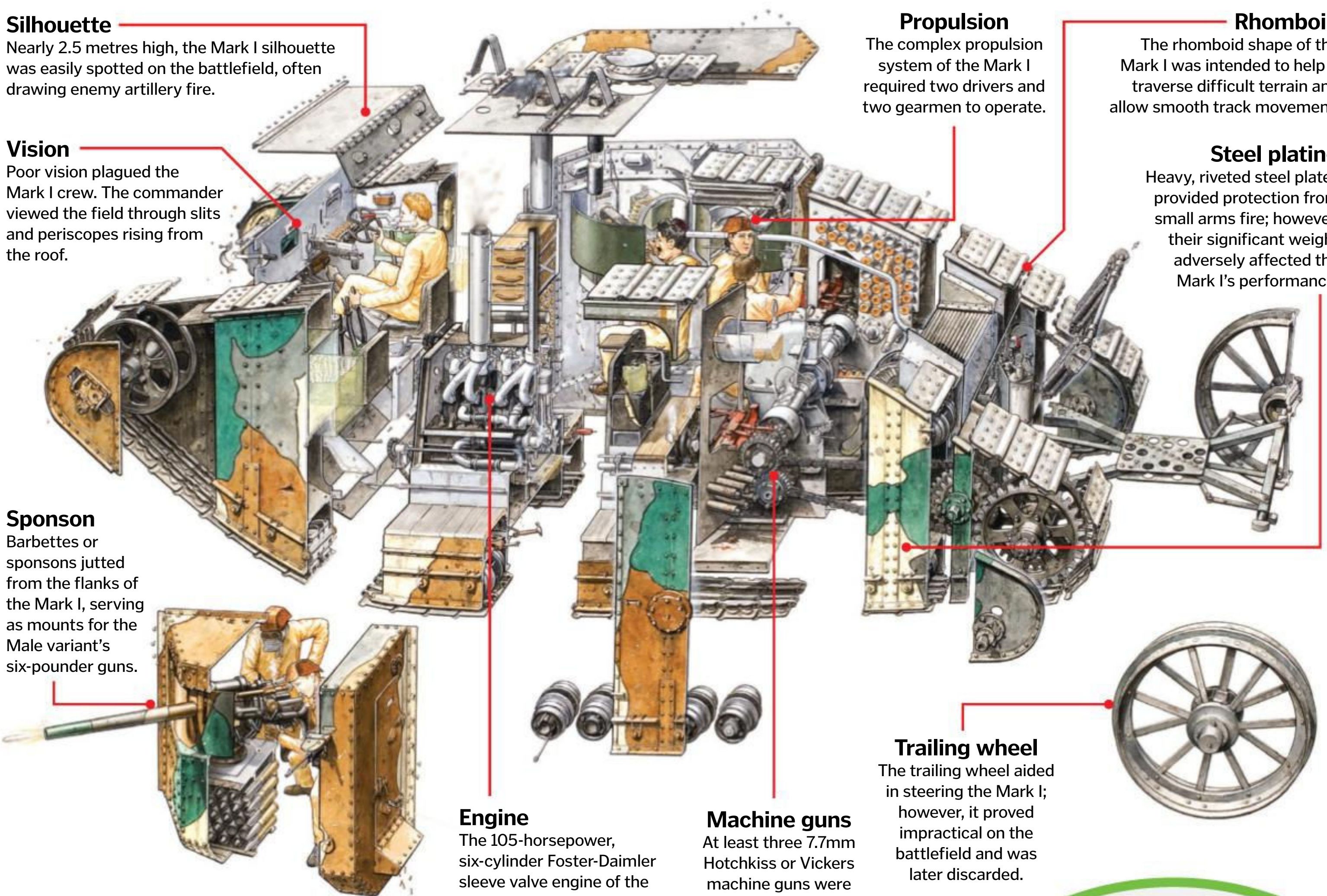
Tanks past and present

How the demands of the modern battlefield have shaped designs

Prior to World War I, research and development yielded some practical benefits in tank design. Caterpillar treads, already in use with heavy tractors, proved superior to wheels, and power to weight ratios were recognised as having significant impact on mobility and performance.

Experimentation with every aspect of the tank's development led to the introduction of basic internal power plants, and sheets of steel were riveted together to form armoured boxes on top of a tractor or car chassis. Visibility and steering were crudely accomplished with hazardous viewing ports and a series of tillers respectively. Machine guns and cannon originally meant for use with infantry and artillery units were also adapted.

Although they were terrifying to the common foot soldier that encountered them, the earliest



1916

Mark I The first tank ended the stalemate of trench warfare

Hopes of breaking the agonising stalemate of trench warfare during World War I led to the accelerated development of the world's first operational tank, the British Mark I. The Landships Committee was established in 1915 by Winston Churchill – First Lord of the Admiralty at the time – to produce an armoured vehicle for the battlefield. The Mark I was the production model of earlier prototypes Little Willie and Mother.

The Mark I weighed just over 28 tons and was powered by a six-cylinder Foster-Daimler engine. It was produced in two variants, the Male mounting two Hotchkiss six-pounder guns and the Female mounting two Vickers machine guns, with both variants sporting an additional three light machine guns.

Eight crewmen shared a common compartment. The British Army placed the first order for 100 Mark I tanks in February 1916, and the tank made its combat debut during the Battle of the Somme. Although several tanks broke down or became stranded, a new era in modern warfare had begun.

A fleet of 36 tanks led an attack at the 1916 Battle of Flers-Courcelette

tanks were heavy and unwieldy contraptions that were prone to mechanical failures. The engines were simply inadequate for propelling the tremendous weight of the vehicle forward. The exhaust fumes from straining engines sometimes even sickened the crews so seriously that they could not function.

The second generation of armoured vehicles reflected the experience of the Great War, and numerous innovations of the interwar years were put to use during World War II. The purpose-built tank chassis was refined, diesel and gasoline engines became more powerful and some were borrowed from the aircraft industry. The rotating turret-mounted machine guns and cannons were introduced and armour protection improved, while communication between tanks was vastly enhanced with reliable radios that replaced hand signals and directional flags.

During the second half of the 20th century and beyond, evolving technology has transformed the tank into a modern marvel of mechanised warfare. Global Positioning Systems (GPS) foster unprecedented coordination of units, while sophisticated infrared target acquisition and stabilisation equipment allow tanks to track multiple targets simultaneously and accurately fire weapons on the move. They also feature state-of-the-art turbine engines combined with composite armour – lighter and many times stronger than steel – for unprecedented speed and security.

Conditions inside a Mark I were hot, noisy and dangerous for the eight-man crew

An American crew awaits orders for a light tank in Coburg, Germany in 1945

M4 Sherman tanks equipped with flame-throwers were deployed by the US in the Battle of Iwo Jima in 1945

The first tanks were designed to break through barbed wire on enemy lines

PRESENT DAY

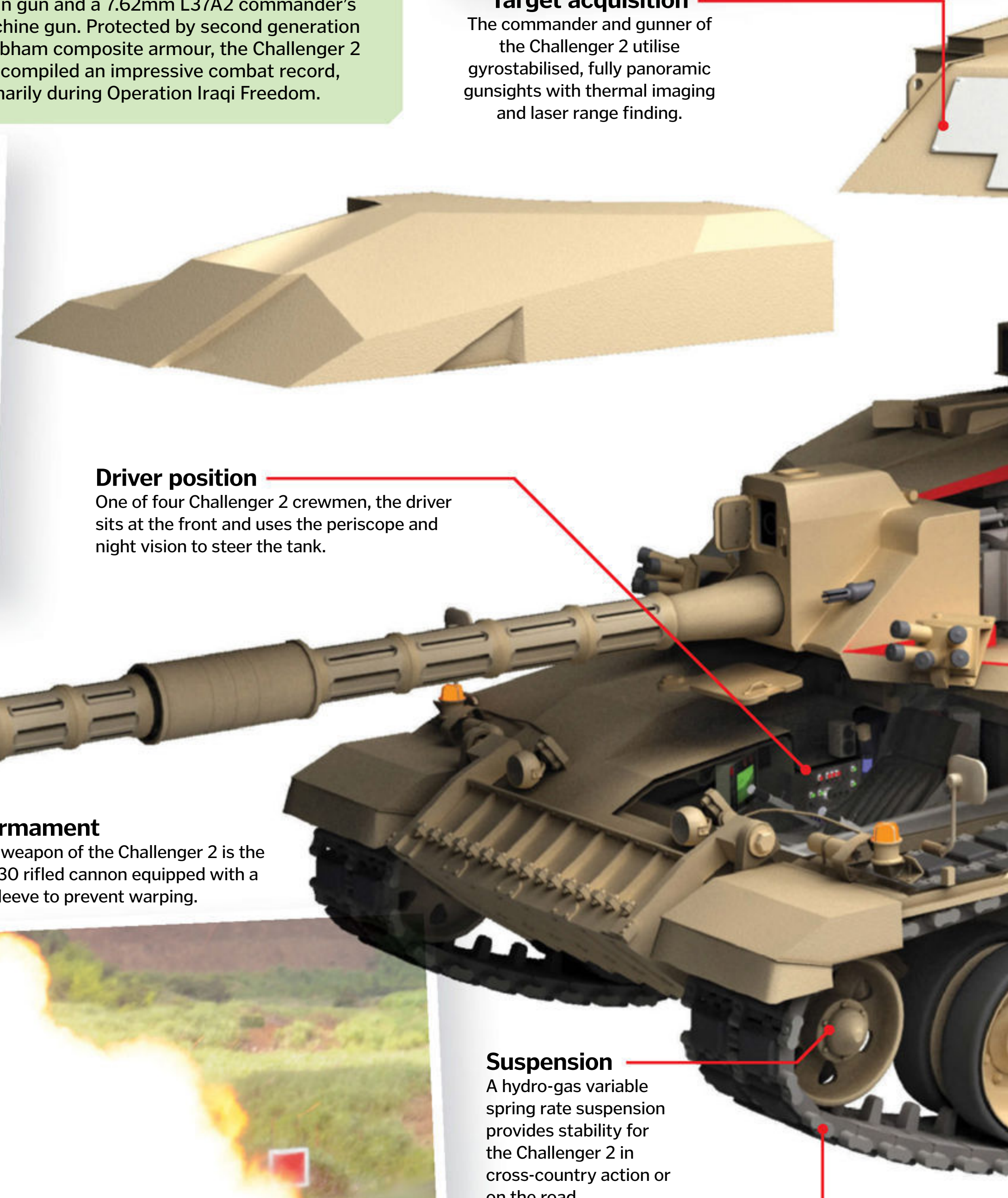
Challenger 2 The main battle tank of the British Army

Considered by many military analysts to be the finest main battle tank in the world today, the development of the British Challenger 2 occurred during a five-year period from 1986 to 1991. Although it shares a common name with its predecessor, the Challenger 1, less than five per cent of the components are compatible.

Designed as a battlefield supremacy tank, the Challenger 2 weighs just under 70 tons and is the first British tank since World War II to be designed, developed, and put into production by a single principal defence contractor, the Land Systems Division of BAE Systems. The main weapon of the Challenger 2 is the 120mm L30 CHARM (CHallenger main ARMament) rifled gun, and control of the turret and gun are maintained through solid-state electronics.

The tank is also equipped with smaller weapons, including a coaxial L94A1 7.62mm chain gun and a 7.62mm L37A2 commander's machine gun. Protected by second generation Chobham composite armour, the Challenger 2 has compiled an impressive combat record, primarily during Operation Iraqi Freedom.

The British Challenger 2 was produced from 1993 to 2002, and approximately 450 units were completed



Target acquisition
The commander and gunner of the Challenger 2 utilise gyrostabilised, fully panoramic gunsights with thermal imaging and laser range finding.

Driver position
One of four Challenger 2 crewmen, the driver sits at the front and uses the periscope and night vision to steer the tank.

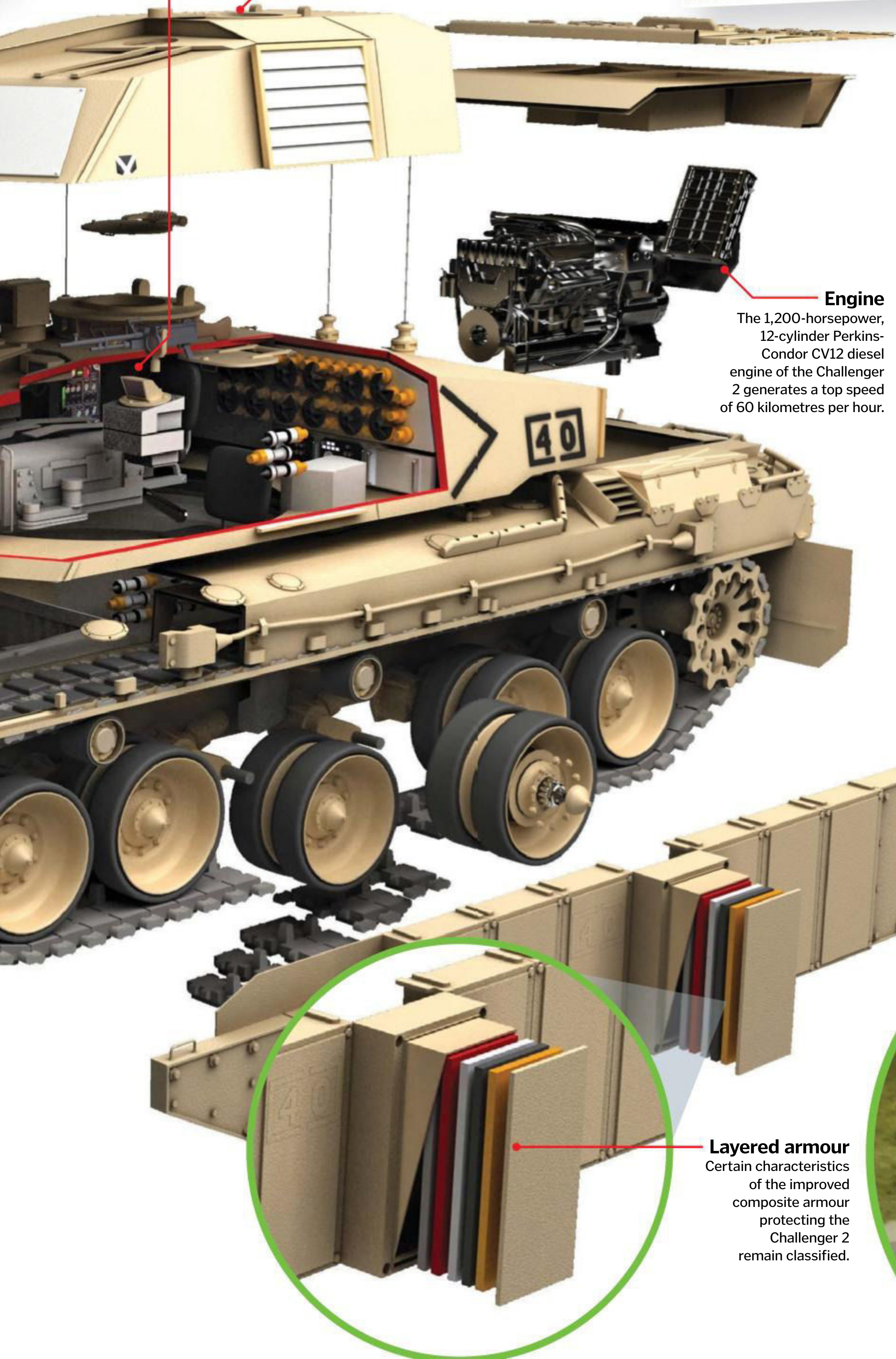
Main armament
The main weapon of the Challenger 2 is the 120mm L30 rifled cannon equipped with a thermal sleeve to prevent warping.

Suspension
A hydro-gas variable spring rate suspension provides stability for the Challenger 2 in cross-country action or on the road.

Tracks
Tension in the Challenger 2's tracks can be hydraulically adjusted from the driver's compartment, to provide excellent mobility on various terrains.

The Japanese Type 90 tank delivers 1,500 horsepower, as much as the Bugatti Chiron, the fastest car in the world

"Technology has transformed the tank into a modern marvel of warfare"



The M1 Abrams has served in the Cold War, Iraq and Afghanistan and is predicted to be in use until 2050

In 2007, Canada borrowed 20 Leopard C2 tanks from Germany to aid their troops in Afghanistan

Despite their high-tech defences, modern tanks can still succumb to enemy fire

Challenger 2 entered service with the British Army in 1998

The modern battlefield

From defence to attack, discover the many roles of tanks in warfare

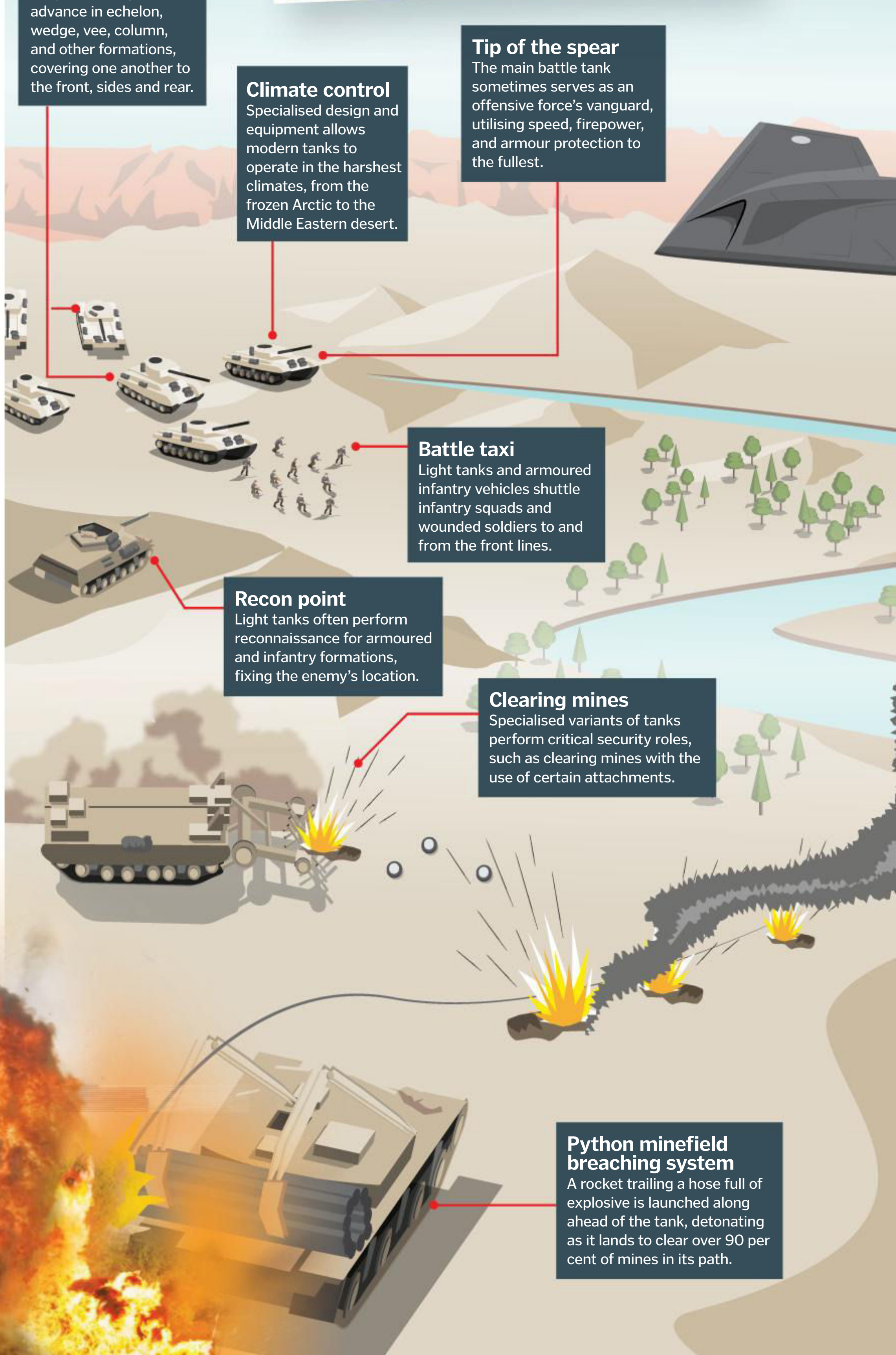
Since their first deployment, tanks have had multiple combat roles. As the world's foremost military organisations began to evaluate the potential of the tank and either embrace or discount its future, military establishments developed their own specific roles for the armoured vehicle.

A division of labour emerged. Tanks were either built with heavy armour and weapons for striking power, or slimmed down for speed and rapid manoeuvre. Even during its infancy, the British Tank Corps fielded heavier Mark IV and Mark V tanks in World War I along with the faster and more manoeuvrable Whippet. The heavier tanks were intended to breach German trenches, creating gaps through which the lighter tanks would slash into enemy areas.

While the heavy tanks struck powerful blows, the light tanks served as modern, armoured cavalry. This tactic continued into World War II, with advanced light, medium, and heavy tanks assuming the roles of their predecessors. Tank versus tank combat became more common, and the growing diversity of operational roles resulted in a variety of armoured vehicles, some designed specifically to destroy enemy tanks.

During the Cold War and into the 21st century, cost concerns and improved technology have fuelled the concept of the main battle tank. With highly efficient engines that deliver substantial power and light composite armour that allows greater speed, the performance gap that previously existed has narrowed. The modern battle tank combines earlier designs into a single, all-round-lethal machine.

A Leopard 2A6 of the German Army speeds across flat terrain

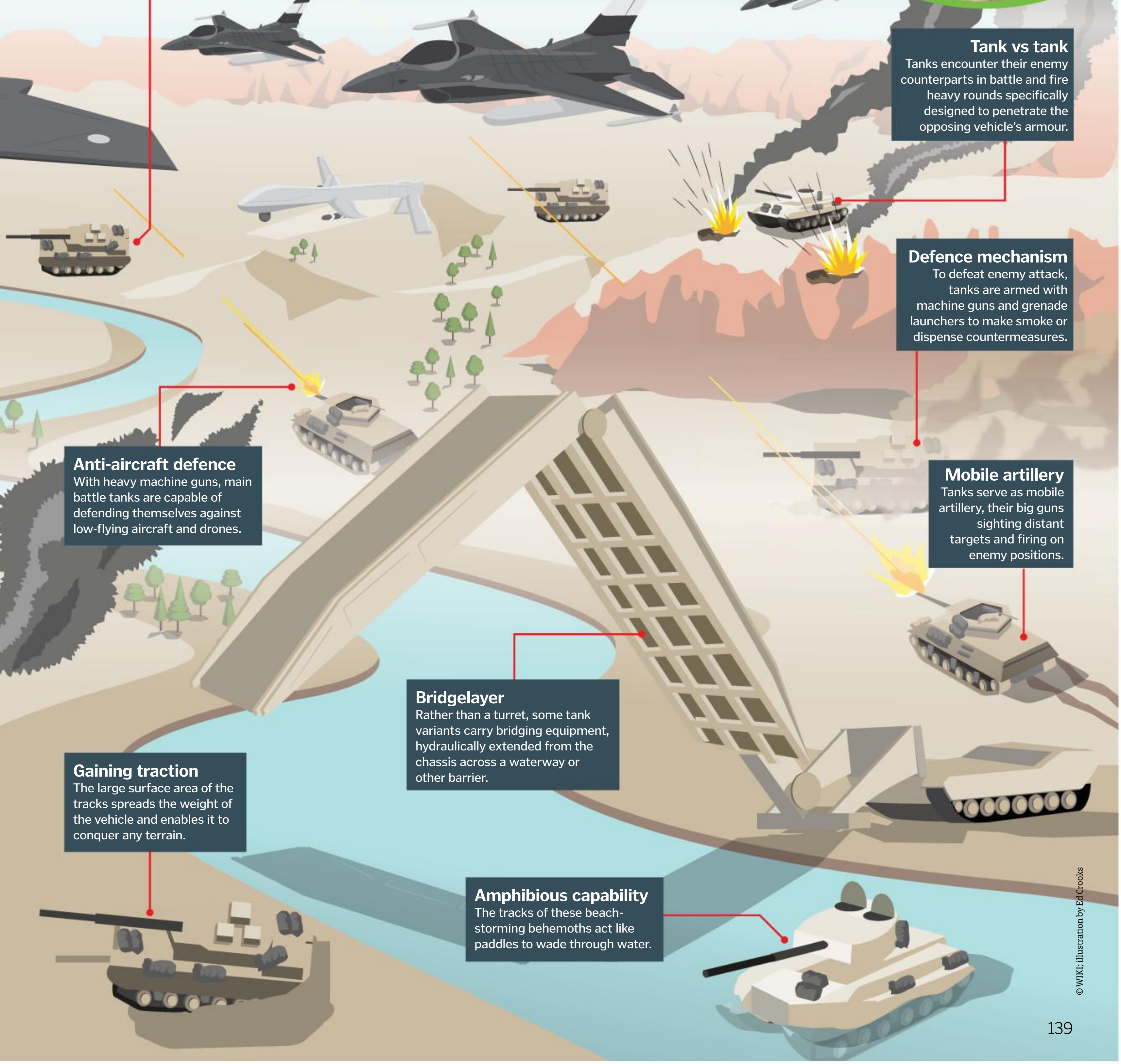


The German Tiger tank could destroy an enemy vehicle from 2km away

Tank roles in battle

"Some vehicles were designed specifically to destroy enemy tanks"

Lying hull down in a prepared revetment, this tank can engage the enemy while protected



Command tank
The commander of a tank formation exerts control on the battlefield, coordinating their unit.

Tank vs tank
Tanks encounter their enemy counterparts in battle and fire heavy rounds specifically designed to penetrate the opposing vehicle's armour.

Defence mechanism
To defeat enemy attack, tanks are armed with machine guns and grenade launchers to make smoke or dispense countermeasures.

Anti-aircraft defence
With heavy machine guns, main battle tanks are capable of defending themselves against low-flying aircraft and drones.

Mobile artillery
Tanks serve as mobile artillery, their big guns sighting distant targets and firing on enemy positions.

Bridgelayer
Rather than a turret, some tank variants carry bridging equipment, hydraulically extended from the chassis across a waterway or other barrier.

Gaining traction
The large surface area of the tracks spreads the weight of the vehicle and enables it to conquer any terrain.

Amphibious capability
The tracks of these beach-storming behemoths act like paddles to wade through water.

Stealth warships

We lift the lid on the latest covert vessels that are taking the art of sneaking to a whole new level

Stealth relies on five core principles when it comes to military vessels: materials, coatings, geometry, noise and tactics. While the latter is situation dependent, the first four are physical qualities that can be modified to enhance stealth with advanced technologies.

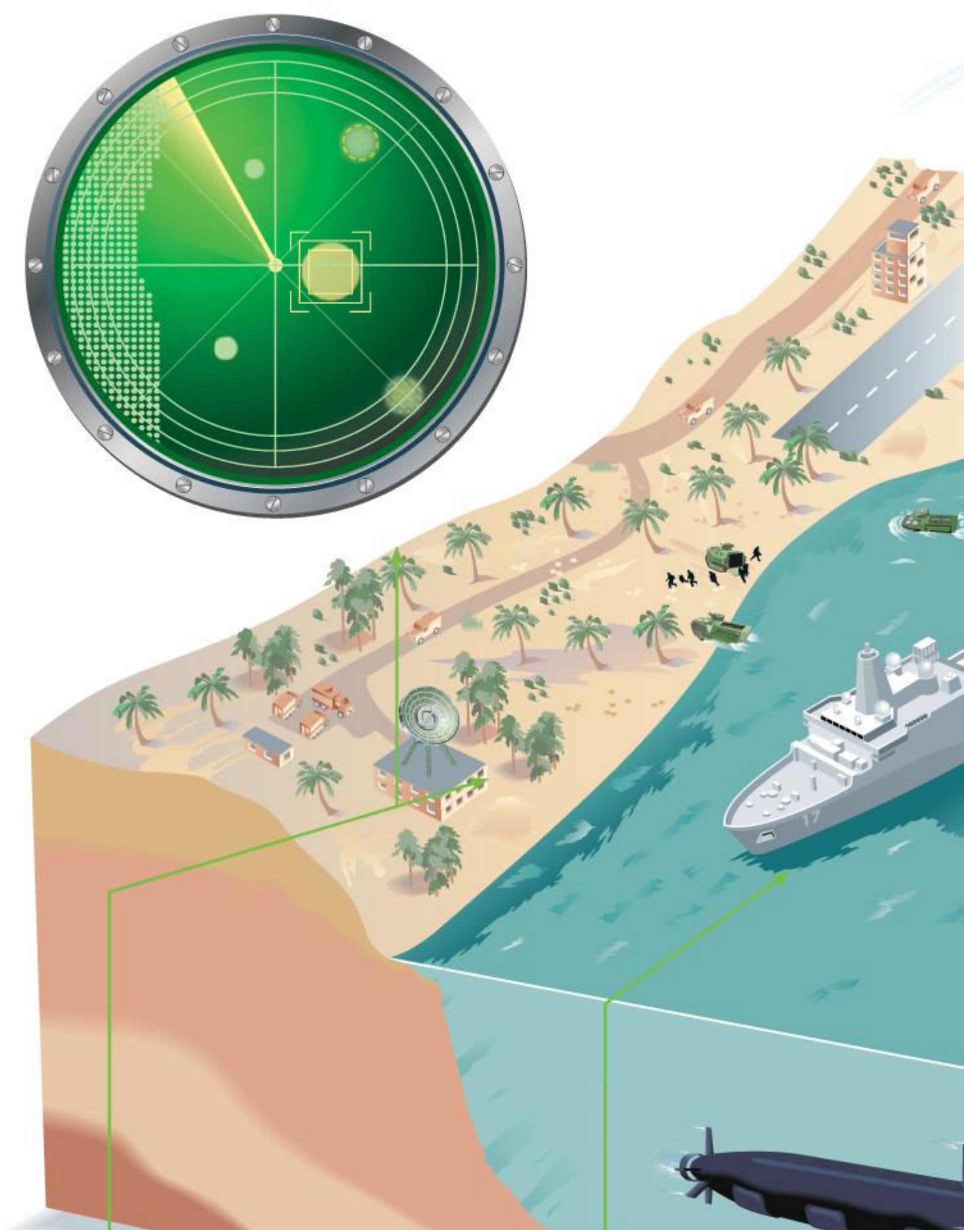
Materials are based on composites such as fibreglass rather than hard metals and the incorporation of negative-index metamaterials (NIMs). These latter artificial substances are designed to be all-but invisible to specific radar frequencies. Some vessels are also being built with demagnetisation belts – a process that involves encircling a ship with superconducting ceramic cables.

Covering a vessel with radar-absorbent coatings such as iron ball paint – tiny spheres of carbonyl iron or ferrite – can also reduce a radar cross-section. Coatings are referred to as RAMs (radar-absorbent materials) and work by transforming radar waves into heat energy. This process works as the carbonyl iron coating has an alternating magnetic field, which when hit by radar waves begins to oscillate at a molecular level, trapping the incoming signal within the material and dissipating its energy as heat.

Geometry is also crucial to remaining undetected. In terms of radar, complex structures offer a far crisper, easier-to-identify return image than those with a simple geometry. As such, modern stealth warships and submersibles are designed with this in mind, often installing protective domes over the mast and sensors, called radomes. Similarly, today's vessels have incredibly clean and angled hulls with few doors and faceted hangars.

Noise in terms of maritime vessels can come courtesy of ship wake, heat generation and operating machinery. In fluid dynamics a wake is the area of disturbed liquid flow downstream of a ship. This wake can be detected by side-scanning synthetic aperture radars (SARs), which can then work out both the ship's position and direction plus sonar installations. To combat this, the latest stealth ships are generally outfitted with low-power diesel motors with specialised heat-dissipation systems to reduce their thermal signature. Active acoustic camouflage systems beneath the hull, meanwhile, can generate a constant series of small bubbles, effectively disrupting sonar images.

Here we explore four examples of cutting-edge military vessels that have been designed with covertness at the top of the priority list, from out-and-out destroyers through to agile, wraith-like submarines.



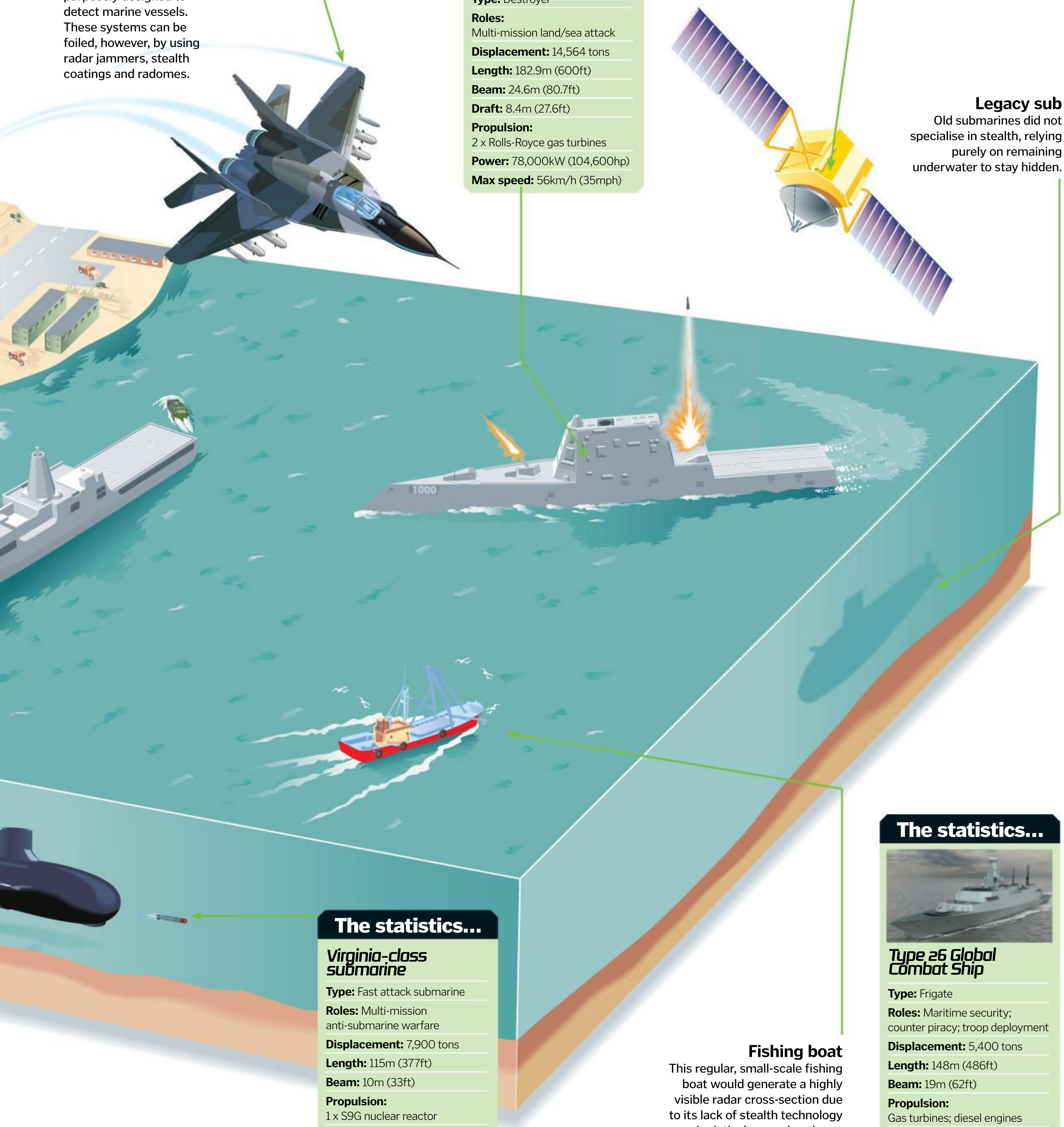
Radar
Ship positions are typically determined through the use of large-scale military radar systems on land, with data passing between them and other local vehicles and facilities. But as stealth tech advances it becomes far harder for radars to spot enemies.

The statistics…

USS San Antonio

Type: Amphibious transport dock
Roles: Troop and vehicle transport; multi-mission littoral combat
Displacement: 24,900 tons
Length: 209m (684ft)
Beam: 32m (105ft)
Draft: 7m (23ft)
Propulsion: 4 x diesel engines
Power: 31,200kW (41,600hp)
Max speed: 41km/h (25mph)

DID YOU KNOW? *The Type 26 frigate has a radar cross-section smaller than a commercial fishing boat!*



Military jet
Some jets are equipped with radar systems purposely designed to detect marine vessels. These systems can be foiled, however, by using radar jammers, stealth coatings and radomes.

The statistics...

USS Zumwalt

Type: Destroyer
Roles: Multi-mission land/sea attack
Displacement: 14,564 tons
Length: 182.9m (600ft)
Beam: 24.6m (80.7ft)
Draft: 8.4m (27.6ft)
Propulsion: 2 x Rolls-Royce gas turbines
Power: 78,000kW (104,600hp)
Max speed: 56km/h (35mph)

Satellite

Legacy sub
Old submarines did not specialise in stealth, relying purely on remaining underwater to stay hidden.

The statistics...

Virginia-class submarine

Type: Fast attack submarine
Roles: Multi-mission anti-submarine warfare
Displacement: 7,900 tons
Length: 115m (377ft)
Beam: 10m (33ft)
Propulsion: 1 x S9G nuclear reactor
Power: 29,828kW (40,000hp)
Max speed: 46km/h (29mph)

Fishing boat
This regular, small-scale fishing boat would generate a highly visible radar cross-section due to its lack of stealth technology and relatively complex shape.

The statistics...

Type 26 Global Combat Ship

Type: Frigate
Roles: Maritime security; counter piracy; troop deployment
Displacement: 5,400 tons
Length: 148m (486ft)
Beam: 19m (62ft)
Propulsion: Gas turbines; diesel engines
Power: Unknown
Max speed: 51km/h (32mph)

The Infiltrator

Type 26 Global Combat Ship

Capable of delivering cruise missiles, combat helicopters, unmanned hunter-killer drones and a barracks load of Royal Marines into coastal warzones, the new Type 26 Global Combat Ship being built by BAE Systems is set to deliver a platform for unprecedented covert operations while at sea. Despite weighing about 5,400 tons and measuring a whopping 148 metres (486 feet) long (that's one and a half times the size of Manchester United's football pitch), the Type 26 appears merely as a small fishing boat on radar systems. This means that when it becomes operational in 2021, it will be able to traverse the globe without detection and infiltrate the most hostile areas. The fishing boat-sized radar cross-section comes courtesy of the sleek, low-profile hull, specially angled deck panels, multi-installation radomes and advanced anti-radar/sonar damping equipment. This tech will cloak on-board vertical missile silos, an array of medium-calibre guns and a huge hangar containing both Merlin and Wildcat helicopters.

USS San Antonio

The USS San Antonio amphibious transport dock excels in its ability to efficiently carry and covertly deliver military vehicles and ground troops. This would not be so impressive if it wasn't for the size of the San Antonio, which weighs in at 25,000 tons – more than the Type 26 and USS Zumwalt combined!

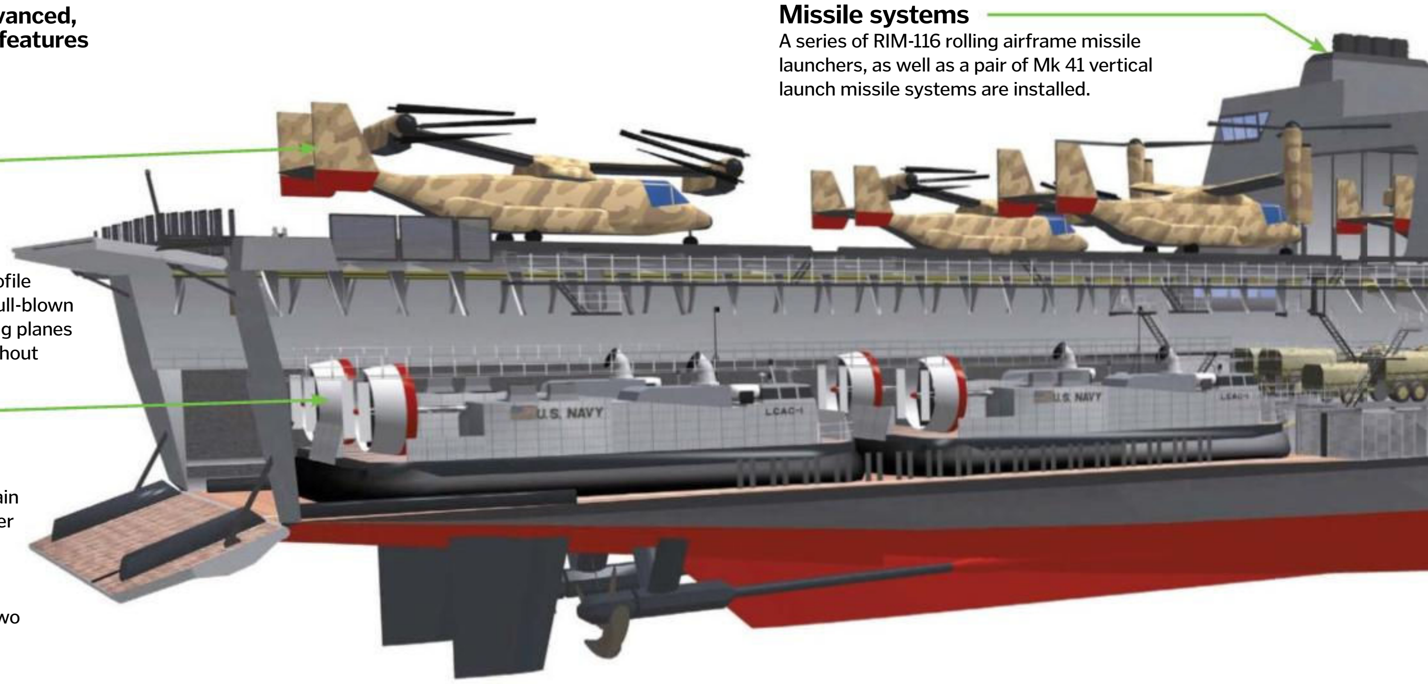
So how is such a gargantuan vessel cloaked? Well, aside from the basics, it comes down to ship-wide attention to detail. Major antennas are mounted on platforms inside two advanced enclosed mast/sensor (AEM/S) systems rather than on yardarms. Deck edges are bounded by shaped bulwarks rather than lifeline stanchions; all exterior equipment is recessed or flush-mounted; bulky things like boat-handling cranes fold down when not in use; while the anchor and anchor hold are designed to minimise radar backscatter.

This strict adherence to stealth principles transforms the radar cross-section of what is essentially a small aircraft carrier into one under half its size. This allows it to sneakily approach target coastlines and launch air-cushioned landing crafts, amphibious assault vehicles, attack helicopters, military jeeps and even armoured personnel carriers onto land along with a maximum 699 soldiers.

The Crusader

The USS San Antonio in focus

Take a look at some of this warship's most advanced, stealth-orientated features



Missile systems
A series of RIM-116 rolling airframe missile launchers, as well as a pair of Mk 41 vertical launch missile systems are installed.

Flight deck
The Antonio's exposed flight deck has a low profile compared to those on full-blown aircraft carriers, enabling planes to be stationed on it without giving away its position.

Well deck
As the San Antonio's main role is to stealthily deliver combat troops and vehicles onto coastal regions, an internal well deck is equipped with two LCAC landing crafts.

The Annihilator

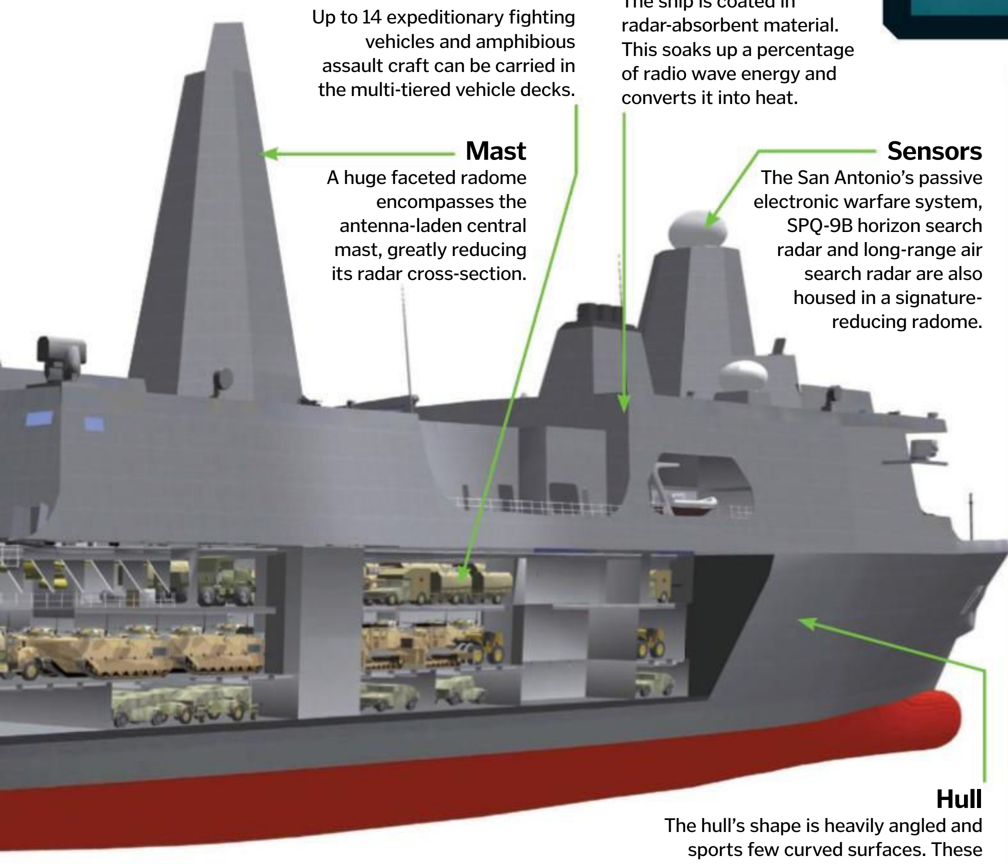
USS Zumwalt

The USS Zumwalt – the lead ship in the upcoming Zumwalt-class of destroyers – doubles down on the Type 26's damage-dealing capabilities while maintaining a purist dedication to staying invisible. Stealth first. Features include an aluminium/glass-fibre composite structure, a wave-piercing hull that leaves almost no wake and an exhaust suppressor to reduce its infrared signature. On top of all this, a high-angle inward sloping exterior, noise reduction system and a trapezoidal, radome-inspired command and control centre make this near-15,000-ton titan nothing but a ghost on radar. This arsenal of stealth technology allows it to slip through the waves like a harpoon, ready to deploy an arsenal of a much more explosive nature on unsuspecting targets.

Interestingly, the Zumwalt even extends its stealth mantra to its weapons, with every gun, missile and torpedo launched by integrated computer systems. As such, far from crew members having to man gun emplacements on deck or load missiles into launchers manually – generating more noise – the Zumwalt allows the sleek, minimalist deck to remain undisturbed, so an offensive can be launched without compromising its location.

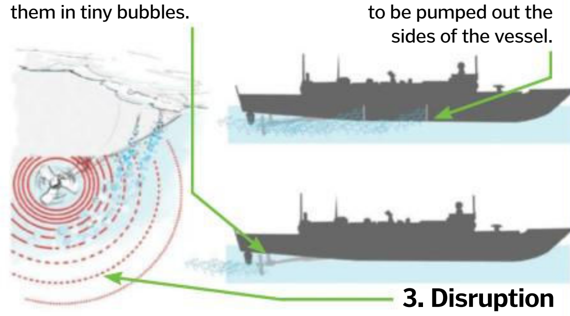
Virginia-class submarine

While the Type 26, USS Zumwalt and USS San Antonio are demonstrating advanced stealth technologies dedicated to reducing their cross-sections to radar, Virginia-class subs are utilising a piece of kit that can do the same for sonar. The Virginia's ultra-low acoustic signature comes courtesy of a special anechoic coating. The coating, which consists of a series of sound-absorbent, rubberised panels that sit on top of the hull work by dampening electromagnetic waves, reducing the number that bounce back and sapping their overall energy. Adding to the Virginia's stealth ability is its revolutionary pump-jet propulsion, which works by drawing water into a turbine-powered pump via an intake then pushing it out at the rear, dramatically muffling noise.



What are masking systems?

Masking systems in marine vehicle applications work by reducing radiated noise generated by the vessel's propulsion system and general movement. This is achieved by mounting machined perforations on the sides and propellers of the ship, through which compressed air is pumped at a high rate. This action creates a barrier of tiny air bubbles around the vessel and propellers that traps mechanical noise and disrupts sonar waves. The result of this is that enemy sonar installations, such as those found on military submarines, receive a heavily distorted image of the scanned area, with vessels commonly shrouded in a pattern akin to rain falling on the ocean surface.



HMS Queen Elizabeth

Take a look inside the Royal Navy's biggest ever vessel

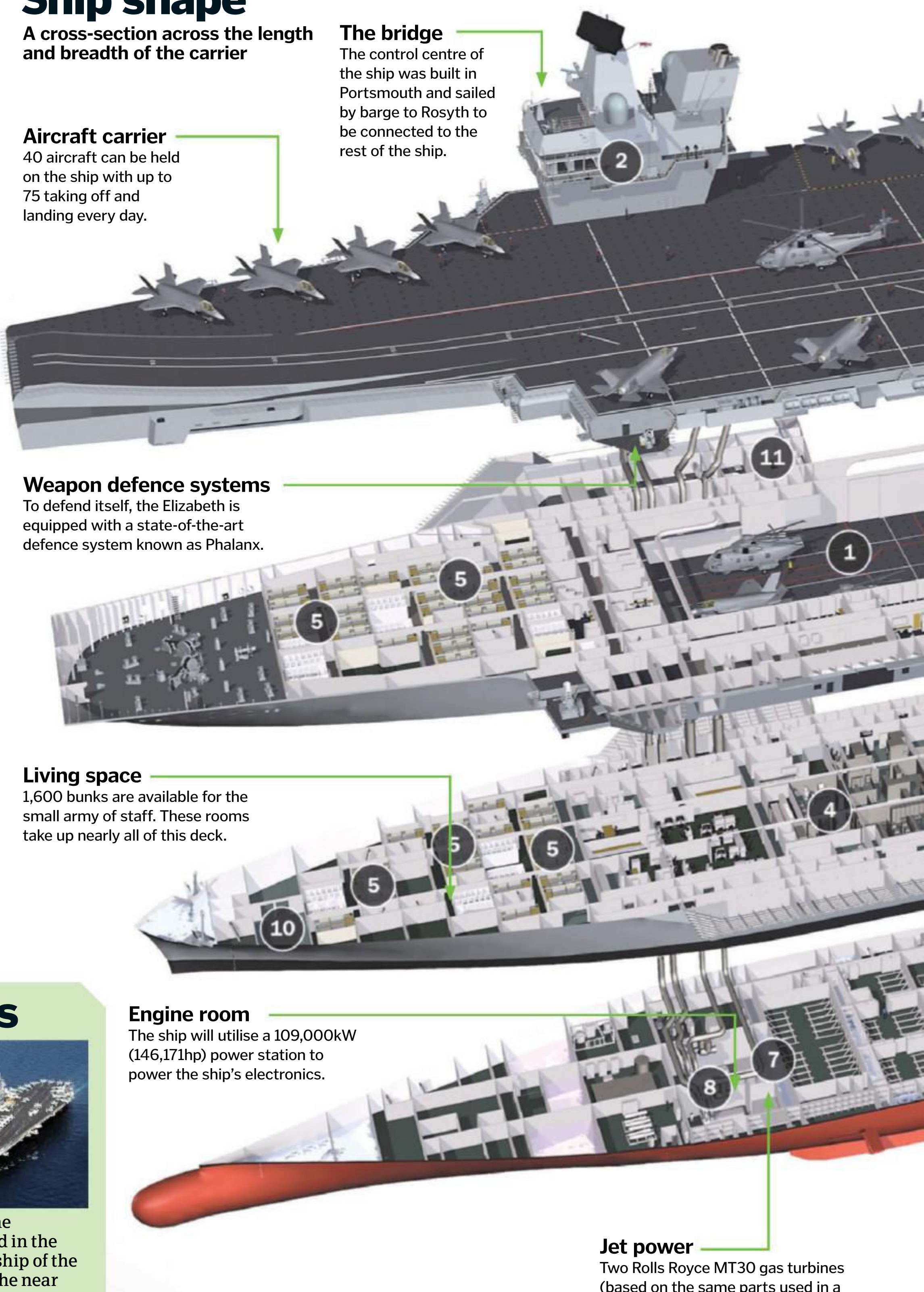
Taller than the Niagara Falls with room for four jumbo jets, the HMS Queen Elizabeth is a true naval goliath. The construction called for six shipyards and 10,000 workers, and it's kitted out with state of the art facilities and tech. As well as a cinema and gym for the 1,600-strong crew to unwind in, the carrier will have the capacity to accommodate up to an incredible 40 aircrafts, including the world's most advanced stealth bomber family, the F35 Lightning II.

In a combat situation it can call on a set of 20mm guns, which are part of an automated Phalanx CIWS (close-in weapon system) that will protect the craft from missiles. If flight is preferred to fight, the two Rolls-Royce MT30 gas turbines and four diesel generator sets give the ship a power of 109,000 kilowatts (146,171 horsepower). That's enough to power a small city! The engines givesthe vessel a top speed of 25 knots (46 kilometres/29 miles per hour) and a range of 16,000 kilometres (10,000 miles).

Incredibly heavy ships – like the Elizabeth – can still float because when the boat is pushing down, the water pushes up. As long as the vessel is not as heavy as the water it has displaced, it will float – a principle called buoyancy. This particular ship will begin sea trials in the summer of 2016. To achieve this, it will have to will have to disembark from its current location in Rosyth Dockyard in Scotland by going under the Forth Bridge. This can only be done at low tide as the HMS Queen Elizabeth is simply too much of a giant to clear it at high tide!

Ship shape

A cross-section across the length and breadth of the carrier



The bridge
The control centre of the ship was built in Portsmouth and sailed by barge to Rosyth to be connected to the rest of the ship.

Aircraft carrier
40 aircraft can be held on the ship with up to 75 taking off and landing every day.

Weapon defence systems
To defend itself, the Elizabeth is equipped with a state-of-the-art defence system known as Phalanx.

Living space
1,600 bunks are available for the small army of staff. These rooms take up nearly all of this deck.

Engine room
The ship will utilise a 109,000kW (146,171hp) power station to power the ship's electronics.

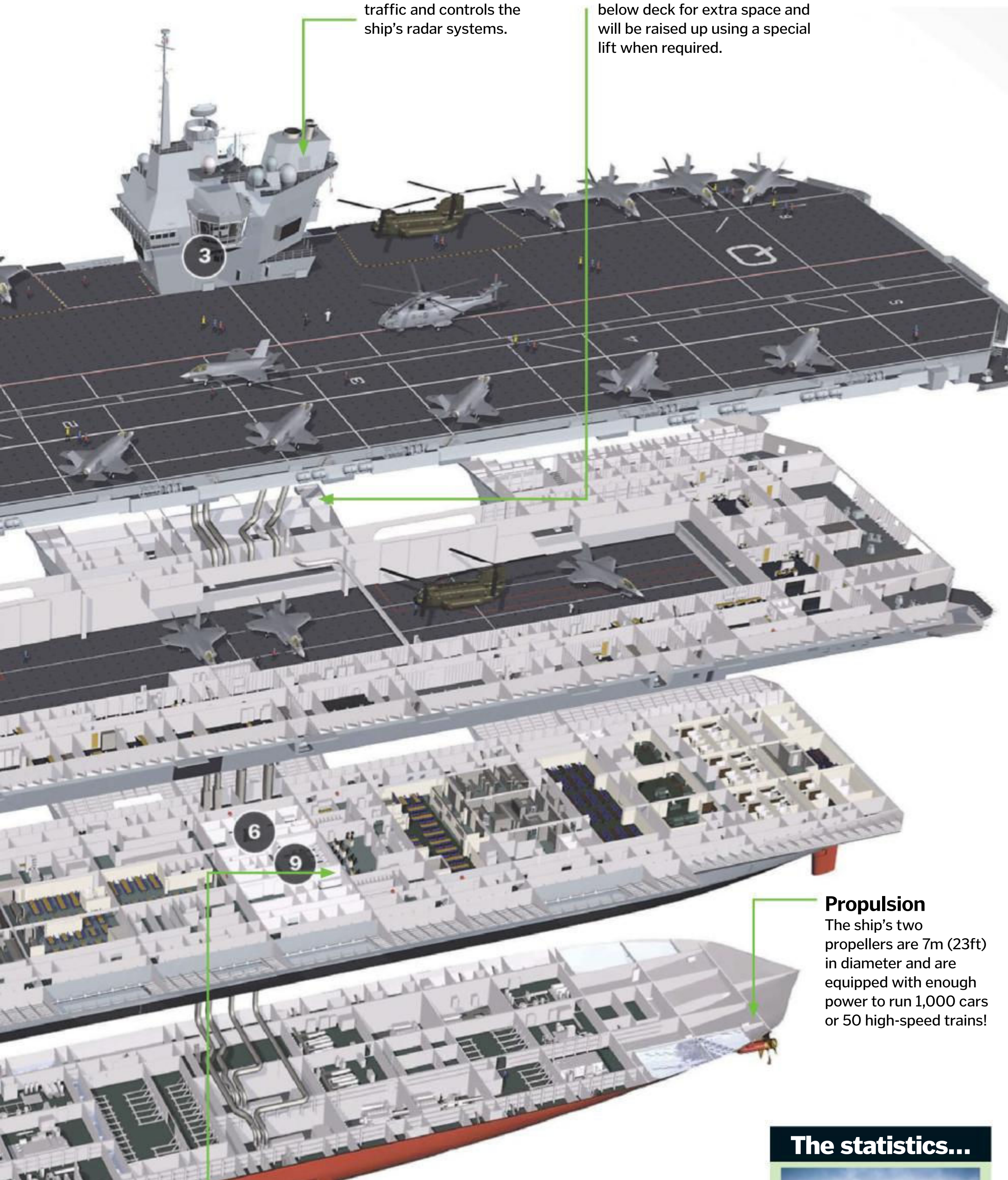
Jet power
Two Rolls Royce MT30 gas turbines (based on the same parts used in a Boeing 777) power the engine along with four diesel engines.

The Invincible class

Before the Queen Elizabeth class was even a twinkle in the Royal Navy's eye, the Invincible class ruled the waves. The first of this class of light aircraft carrier was the HMS Invincible itself, which was first commissioned in 1980. Followed by the HMS Illustrious and HMS Ark Royal, the vessels served during the Falklands War and the Bosnian War and assisted in the 2003 invasion of Iraq. The Illustrious is the only ship of the class still in service but it is due to be retired in the near future. It will possibly be turned into a tourist attraction in Hull, hosting events and exhibitions on the River Humber.

Flight control
This tower regulates air traffic and controls the ship's radar systems.

Aircraft lift and hangar
Several aircraft will be placed below deck for extra space and will be raised up using a special lift when required.



Propulsion
The ship's two propellers are 7m (23ft) in diameter and are equipped with enough power to run 1,000 cars or 50 high-speed trains!

Medical area
The ship contains various medical areas as well as a hospital to treat staff on long journeys.

The statistics…

HMS Queen Elizabeth

Cost: £6.2 billion ($10.3 billion)

Weight: 65,000 tons

Length: 280m (919ft)

Height: 56m (184ft)

Crew: 1,600

The original HMS Queen Elizabeth

In the early-20th century, dreadnoughts were the battleships of choice. The original Queen Elizabeth class was a series of five super-dreadnoughts that served the Royal Navy through both world wars. Six were designed but HMS Agincourt was cancelled due to the outbreak of World War I. The vessels all made it through both world wars except HMS Barham, which was sunk by a German submarine in 1941. By this time the armour of the vessels had become obsolete and could not protect against torpedo fire. They were deployed all over the world before being effectively replaced by the Revenge class of battleships and were scrapped in the late-1940s.

The first HMS Queen Elizabeth was the flagship of the Royal Navy, serving for 34 years

12,000
CANS OF BAKED BEANS ON BOARD, ENOUGH TO FILL 38 BATHTUBS

64,800
EGGS ON BOARD ENOUGH FOR 21,600 OMELETTES

66,000
SAUSAGES IN THE SHIP'S STORES – THAT'S 6.5KM (4MI) WORTH

1,000
LOAVES OF BREAD PRODUCED A DAY BY THE SHIP'S ONBOARD BAKERY

The British Type 45 has a displacement of 8,000 tons and can carry a crew of around 190

NEXT-GEN BATTLESHIPS

The firepower on the latest battleships is mind-boggling. We explore the technology transforming 21st-century naval warfare

If you thought that the golden age of naval combat came to an end 200 years ago, then clearly somebody forgot to tell the national navies of today. In fact, a wave of state-of-the-art, armed-to-the-teeth battleships are currently emerging from shipbuilding yards with a singular aim in mind: total domination of the seas.

From the brand-new and brutal Type 45 destroyers being pushed out of British dockyards, through to the almost sci-fi Zumwalt-class battleships emerging in the USA, and on to the cruising carrier vessels sitting like small islands in Earth's oceans, battleships are being produced en masse and to a more advanced spec than ever before.

Far from the basic heavyweights of bygone centuries, required simply to go toe-to-toe with each other in a deadly game of broadsides, today's warships need to take down a variety of threats, whether at sea, on land or in the air, and they need to do so at extreme range. As such, step onto a battleship today – be it a frigate, destroyer or corvette – and you'll find an arsenal of insane weapons systems.

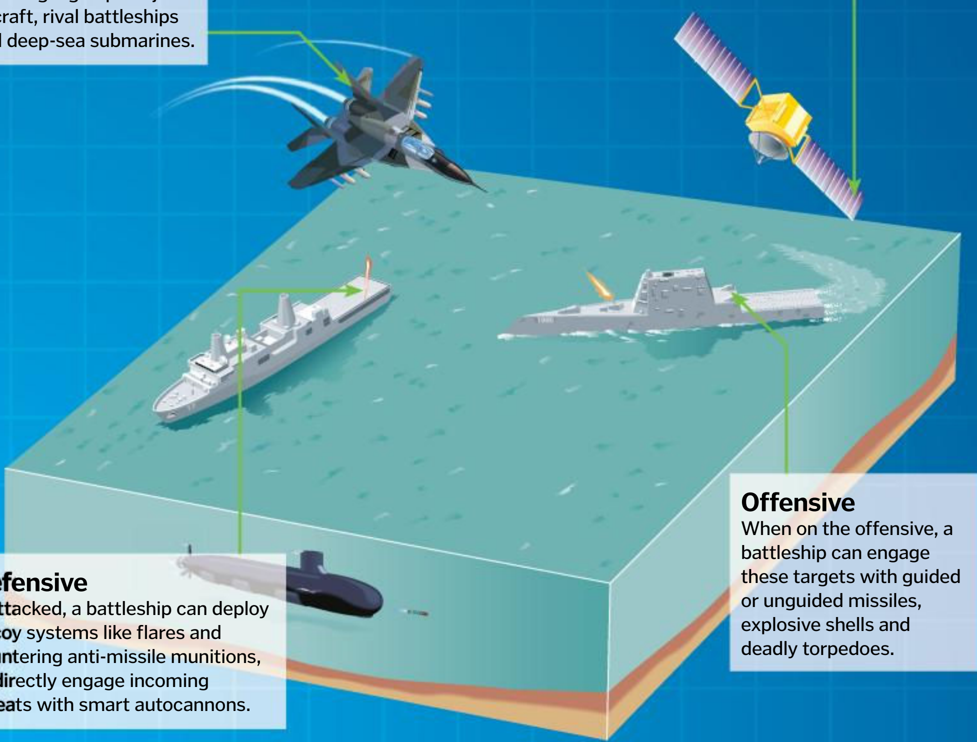
There are cannons that can fire over distances of 95 kilometres (60 miles) and deliver a guided smart munition to a target with pinpoint accuracy, as well as Gatling guns that can automatically track a target moving at hundreds of miles per hour and then fire explosive bullets at up to 1,100 metres (3,610 feet) per second to take it down.

Missile launch systems not only increase the vessel's stealth but are capable of launching a wide variety of city block-levelling missiles directly into the heart of enemy encampments in minutes from a safe distance, while naval guns are capable of subjecting a target to continuous bombardment with high-explosive shells with controlled abandon. All this is but a taste of the weaponry being fitted to the most advanced 21st-century warships.

The heavy armament of vessels currently knows no bounds, with even coastguard fleets, convoy vehicles and civilian support ships being outfitted with some form of military-grade offensive weaponry. Clearly, controlling the world's waters is not as old-fashioned as the history books would have us believe. In this feature we take a look at the various types of battleship taking to the seas and the weapon systems that are revolutionising not just naval combat but warfare in general.

Rules of engagement

The key stages and technology that decide the outcome of a modern naval battle



Threats
Modern battleships are designed to engage a number of threats, including high-speed jet aircraft, rival battleships and deep-sea submarines.

Detection
To engage any of these targets first they need to be detected – something achieved via orbiting GPS satellites, radar and sonar communication systems.

Defensive
If attacked, a battleship can deploy decoy systems like flares and countering anti-missile munitions, or directly engage incoming threats with smart autocannons.

Offensive
When on the offensive, a battleship can engage these targets with guided or unguided missiles, explosive shells and deadly torpedoes.

A high-explosive guided torpedo is projected from a US battleship

More traditional 41cm (16in) naval guns on board the USS North Carolina

USS Iowa unloads a volley of explosive shells from its Mark 7 naval guns

Battleship types

1 Corvette
One of the smallest types, the corvette is a lightly armed and manoeuvrable vessel used for coastal operations. Stealth corvettes are now becoming popular too.

2 Frigate
Lightly armed, medium-sized ships generally used to protect other military or civilian vessels. Recently, frigates have been re-focused to take out submarines.

3 Destroyer
Large and heavily armed, destroyers are typically outfitted for anti-submarine, anti-aircraft and anti-surface warfare, and can remain at sea for months on end.

4 Cruiser
The cruiser is an armed-to-the-teeth multi-role vessel akin to a modern destroyer. While cruisers are still in use, they have largely been superseded now.

5 Carrier
Ocean-going leviathans, carriers are the largest battleship. Their primary role is as a seagoing airbase, launching combat aircraft, but they also come heavily armed.

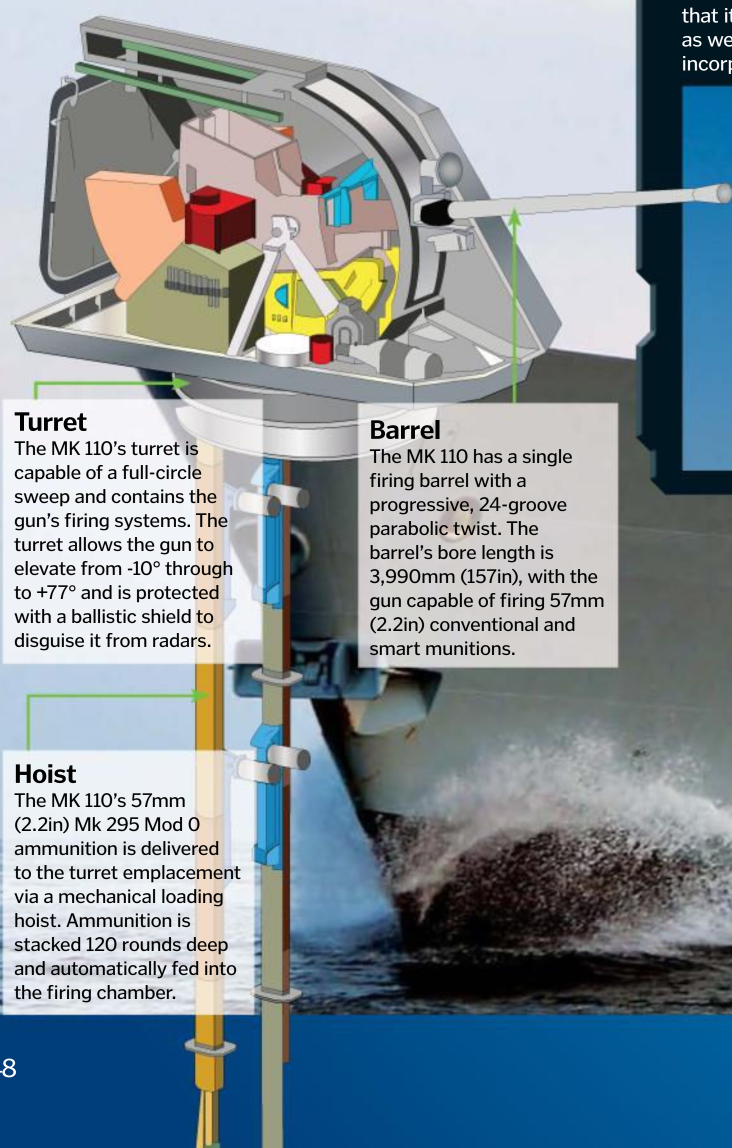
Weapons in focus

We train our sights on four of the most advanced armaments aboard the latest battleships

Mk 110 naval gun

FIRE POWER 3

Capable of delivering automatic salvos of 220 57-millimetre (2.2-inch) Mk 295 Mod 0 ammunition – read: fragmenting high-explosive shells – each and every minute, the Mk 110 naval gun is quite simply a shell-slinging colossus. Stemming from one of the most long-lasting naval gun series of the last 100 years, the Mk 110 comes with a selection of hot features. These include the ability to fire both standard and smart munitions, a gun barrel-mounted radar for refined measuring of muzzle velocity, an instantaneous ability to switch between ammunition types, a stealth-oriented ballistic shield that protects the gun while allowing a full 360-degree traverse, plus a fully digital fire control system that enables the Mk 110 to respond to exact pointing orders and ammunition fuse selection milliseconds prior to firing. Indeed, the only thing that stops the Mk 110 from bombarding its target continuously is its shell capacity, which rests at 120 rounds with a three-minute reload process.



Turret
The MK 110's turret is capable of a full-circle sweep and contains the gun's firing systems. The turret allows the gun to elevate from -10° through to +77° and is protected with a ballistic shield to disguise it from radars.

Barrel
The MK 110 has a single firing barrel with a progressive, 24-groove parabolic twist. The barrel's bore length is 3,990mm (157in), with the gun capable of firing 57mm (2.2in) conventional and smart munitions.

Hoist
The MK 110's 57mm (2.2in) Mk 295 Mod 0 ammunition is delivered to the turret emplacement via a mechanical loading hoist. Ammunition is stacked 120 rounds deep and automatically fed into the firing chamber.

Advanced Gun System

FIRE POWER 4

The Advanced Gun System (AGS) is a new naval gun from BAE Systems capable of firing precision munitions super-fast and at over-the-horizon ranges. What makes it special is that far from firing traditional unguided shells – as most naval guns have been designed for – it fires the Long Range Land Attack Projectile (LRLAP), a 155-millimetre (6.1-inch) precision guided artillery shell that, thanks to base bleed rocket assistance and an extended range fin glide trajectory, can travel over 105 kilometres (65 miles) to a target. What's more, it then has a circular error probable (ie accuracy) of only 50 metres (164 feet), making it incredibly precise even at great distance. Throw in the fact that the AGS can fire ten of these LRLAPs per minute from its stealth-designed turret and that it can fire traditional unguided munitions as well and it becomes clear why it's being incorporated into many of today's warships.

Vertical Launch System

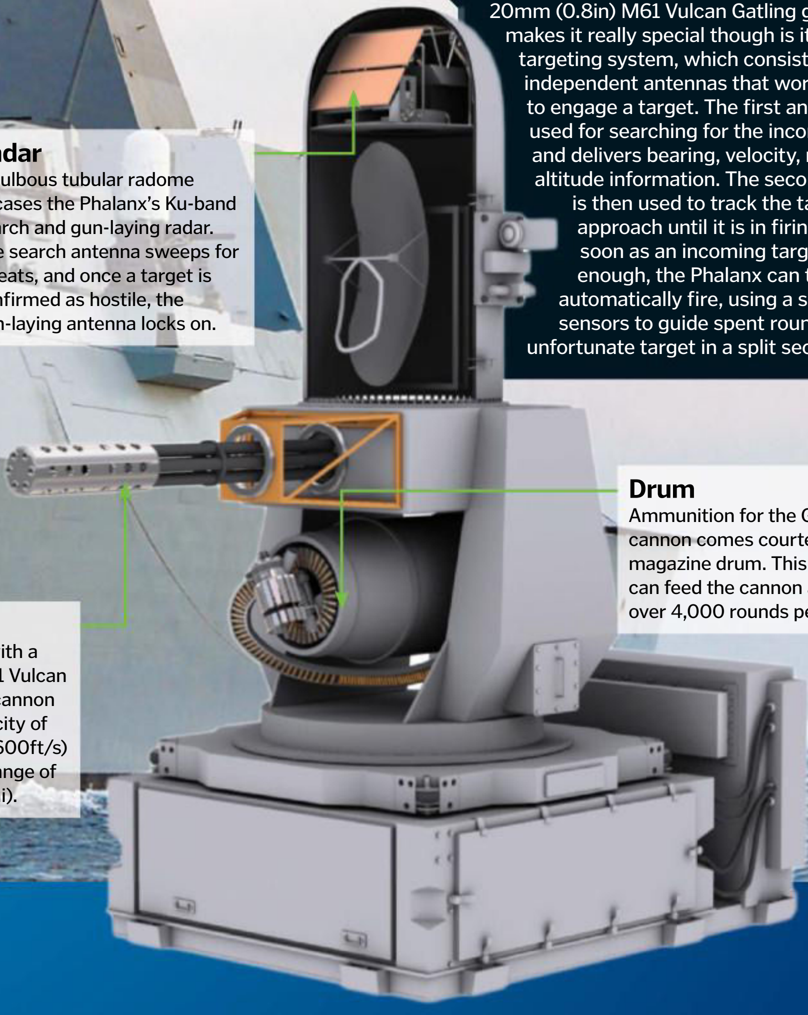
FIRE POWER 5

The Vertical Launch System (VLS) is a state-of-the-art multi-missile launching system. Unlike previous systems, which could only fire one specific type of missile, the VLS is modular so a variety of projectiles can be fired from the same enclosures. The missiles, which on the Zumwalt-class destroyers include the RIM-162 Evolved Seasparrow missile, Anti-Submarine Rocket (ASROC) and Tactical Tomahawk subsonic cruise missile, are enclosed in a series of launch cells within the ship's hull and, when launched, are fired out of the top of the deck. By concealing the missiles within the ship until needed, the VLS improves the ship's overall radar cross-section, making it harder to detect. Each missile fired from a VLS cell is of the guided variety, with a selection of high-explosive warheads directed to the target by radar or GPS.

Phalanx CIWS

FIRE POWER 3

Every battleship built today comes with a close-in weapon system, or CIWS, and out of these systems the Phalanx CIWS is the leader of the pack. It is a point-defence weapon designed to attack any target – be that enemy fighter jets or missiles – which has managed to evade the battleship's longer-range offensive weapons with its massive 20mm (0.8in) M61 Vulcan Gatling gun. What makes it really special though is its advanced targeting system, which consists of two independent antennas that work together to engage a target. The first antenna is used for searching for the incoming target and delivers bearing, velocity, range and altitude information. The second antenna is then used to track the target on its approach until it is in firing range. As soon as an incoming target is close enough, the Phalanx can then automatically fire, using a selection of sensors to guide spent rounds at the unfortunate target in a split second.



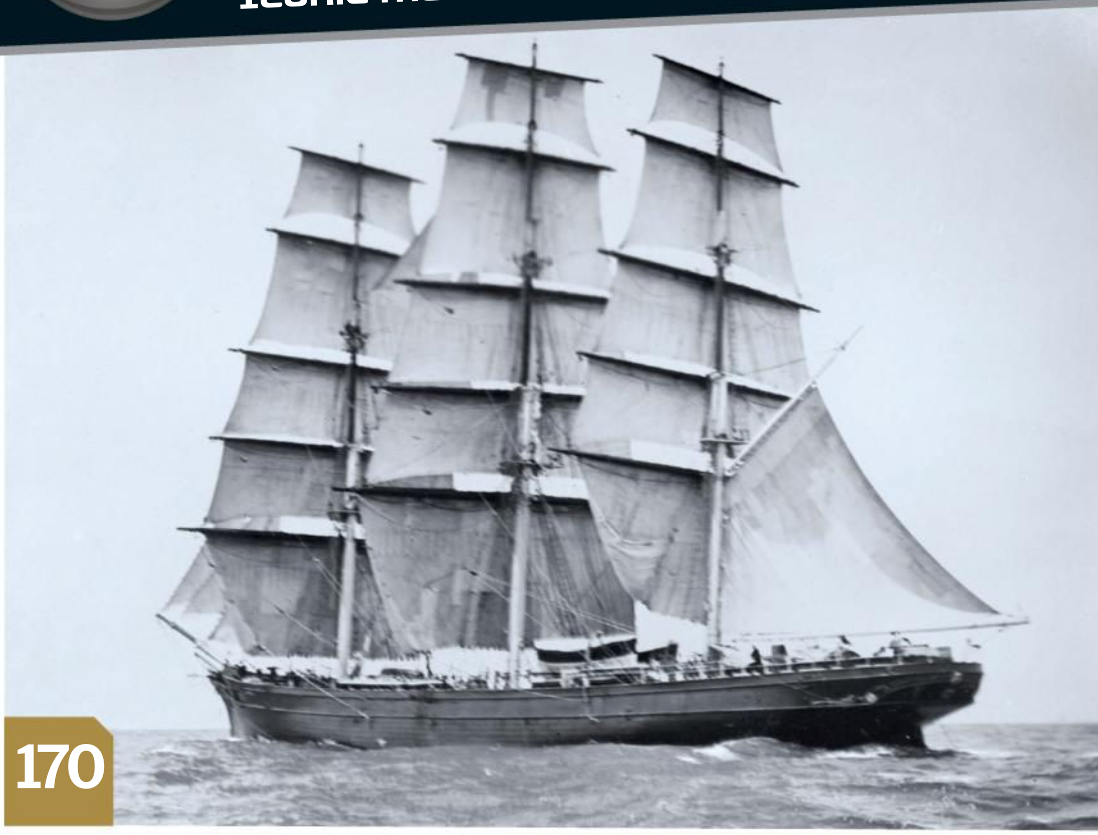
Radar
A bulbous tubular radome encases the Phalanx's Ku-band search and gun-laying radar. The search antenna sweeps for threats, and once a target is confirmed as hostile, the gun-laying antenna locks on.

Drum
Ammunition for the Gatling cannon comes courtesy of a large magazine drum. This dispenser can feed the cannon at a rate of over 4,000 rounds per minute.

Gun
Damage is dealt with a 20mm (0.8in) M61 Vulcan autocannon. The cannon has a muzzle velocity of over 1,100m/s (3,600ft/s) and an effective range of up to 3.6km (2.2mi).

HOW IT WORKS HISTORIC

Iconic machines that changed the world



"The Mayflower was often regarded as a symbol of religious freedom in the United states"

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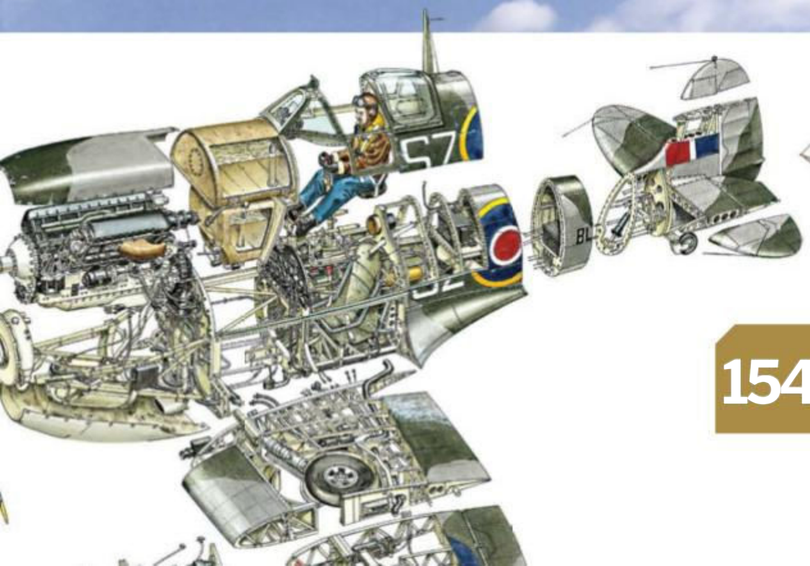

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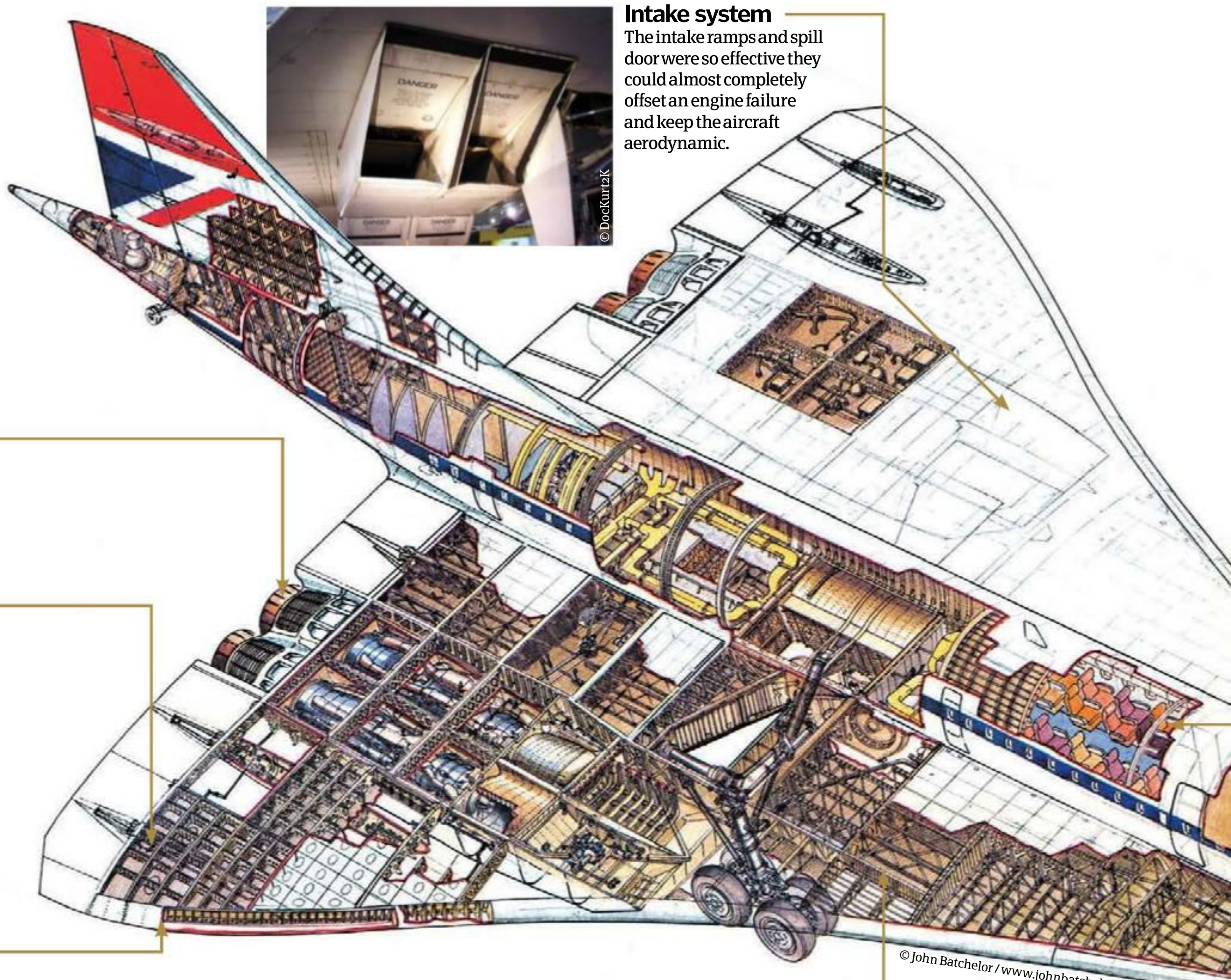
Inside Concorde

What's under the wings?



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Intake system
The intake ramps and spill door were so effective they could almost completely offset an engine failure and keep the aircraft aerodynamic.

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Rolls-Royce/Snecma Olympus 593 engines
Concorde's afterburning engines were a development of engines originally designed for the Avro Vulcan bomber.

Wing fuel tanks
Concorde, like many aircraft, stored its fuel in its wings. However, it also used its fuel as a heat sink, drawing heat away from the passengers.

Ogival wings
Concorde's 'double delta' wings helped its aerodynamic profile and speed.

Lighter, stronger components
Concorde was constructed using 'sculpture milling', a process that reduced the amount of parts required while making those that were necessary lighter and stronger.

Concorde

An aircraft that could fly across the Atlantic in under three hours seemed as impossible as it was desirable

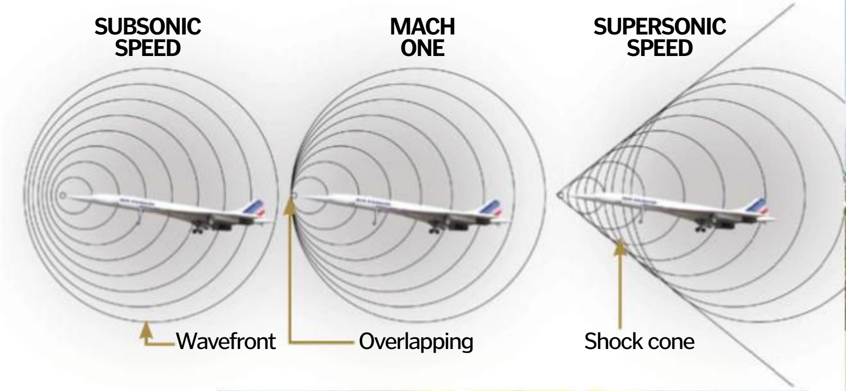
Flying faster than the speed of sound has always been the sole proviso of the military, but in the late-Sixties, Russia, France, the UK and the US were all working on the idea of supersonic commercial travel.

Concorde was the result of France and the UK combining their efforts to produce a supersonic airliner and, even now, it's impossible not to be impressed by its pioneering stature. Its ogival or double-curved wings kept it aerodynamic and dictated much of the plane's shape, as they forced the nose up on taxiing, take off and landing. To help minimise drag on the aircraft as well as improve visibility, the nose cone could move, dropping down to improve visibility then straightening out in flight to improve the aerodynamic profile.

Concorde's engines also had to be modified for extended supersonic flight. Jet engines can only take in air at subsonic speed so the air passing into the engines had to be slowed when flying at Mach 2.0. Worse, the act of slowing the air down generated potentially damaging shock waves. This was controlled by a pair of intake ramps and an auxiliary spill door that could be moved during flight, slowing the air and allowing the engine to operate efficiently. This system was so successful that 63 per cent of Concorde's thrust was generated by these intakes during supersonic flight.

The sonic boom

Sonic booms are generated by the passage of an object through the air. This passage creates pressure waves that travel at the speed of sound. The closer the aircraft gets to the speed of sound, the closer these waves become until they merge. The aircraft then forms the tip of a 'Mach cone', the pressure wave at its nose combining with the fall in pressure at its tail as it passes to create the distinctive 'boom' sound.



This Concorde is on display at Paris-Charles de Gaulle airport

End of an era

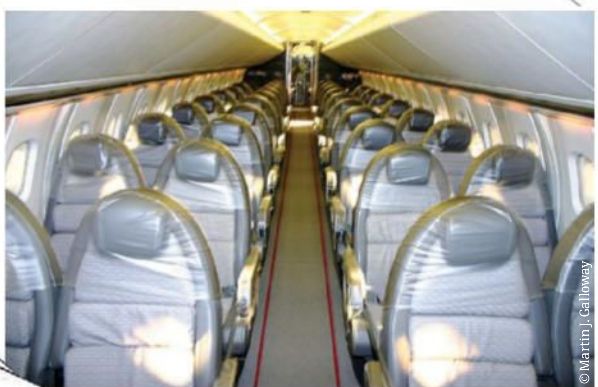
On 25 July 2000, Air France Flight 4590 crashed in Gonesse, France, killing all 100 passengers and nine crew as well as a further four on the ground.

Although the crash was caused by a fragment from the previous aircraft to take off, passenger numbers never recovered and were damaged still further by the rising cost of maintaining the ageing aircraft and the slump in air travel following the 9/11 attacks.

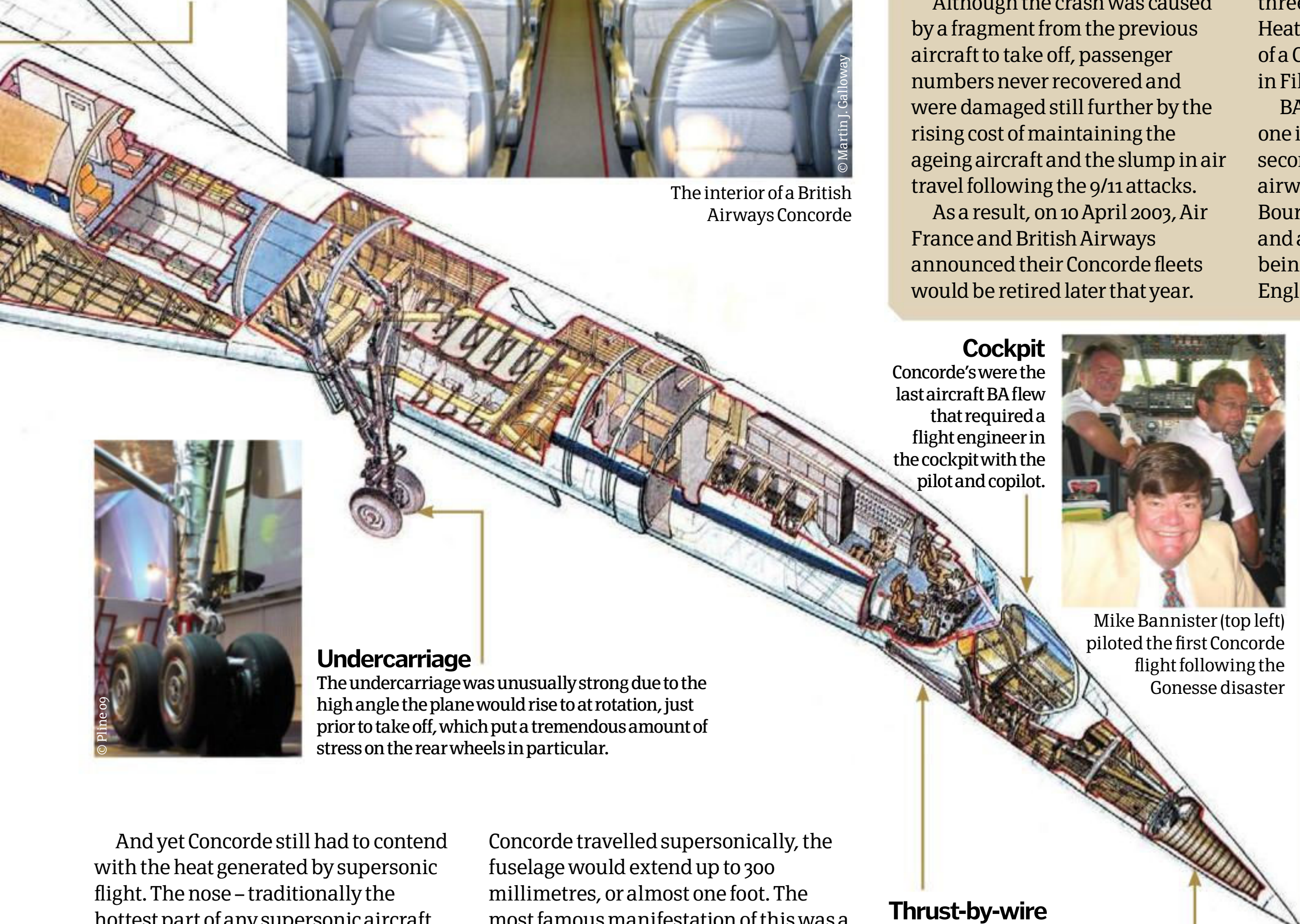
As a result, on 10 April 2003, Air France and British Airways announced their Concorde fleets would be retired later that year.

Despite an attempt by Richard Branson to purchase BA's Concorde fleet for Virgin Atlantic, the planes were retired following a week-long farewell tour that culminated in three Concordes landing at Heathrow, and the very final flight of a Concorde worldwide landing in Filton, Bristol.

BA still owns its Concorde fleet: one is on display in Surrey, a second is being kept near-airworthy by volunteers at the Le Bourget Air and Space Museum, and a third, also at that site, is being worked on by a joint team of English and French engineers.



The interior of a British Airways Concorde



Passenger cabin
Concorde could carry 92 passengers or be reconfigured internally to carry up to 120.

Undercarriage
The undercarriage was unusually strong due to the high angle the plane would rise to at rotation, just prior to take off, which put a tremendous amount of stress on the rear wheels in particular.

Cockpit
Concorde's were the last aircraft BA flew that required a flight engineer in the cockpit with the pilot and copilot.

Mike Bannister (top left) piloted the first Concorde flight following the Gonesse disaster

Thrust-by-wire
Concorde was one of the first aircraft to use an onboard computer to help manage its thrust levels.

Nose
Concorde's nose drooped to help visibility on take off and landing and straightened in flight.

And yet Concorde still had to contend with the heat generated by supersonic flight. The nose – traditionally the hottest part of any supersonic aircraft – was fitted with a visor to prevent the heat reaching the cockpit while the plane's fuel was used as a heat sink, drawing heat away from the cabin.

Even then, owing to the incredible heat generated by compression of air as Concorde travelled supersonically, the fuselage would extend up to 300 millimetres, or almost one foot. The most famous manifestation of this was a gap that would open up on the flight deck between the flight engineer's console and the bulkhead. Traditionally, engineers would place their hats in this gap, trapping them there after it closed.

The statistics…

BAC/Aerospatiale Concorde

Manufacturer: BAC (Now BAE Systems) and Aerospatiale (Now EADS)

Year launched: 1976

Year retired: 2003

Number built: 20

Dimensions:
Length: 61.66m
Wingspan: 25.6m
Height: 3.39m

Capacity (passengers): Up to 120 passengers

Unit cost: £23 million in 1977

Cruise speed: Mach 2.02 (1,320mph)

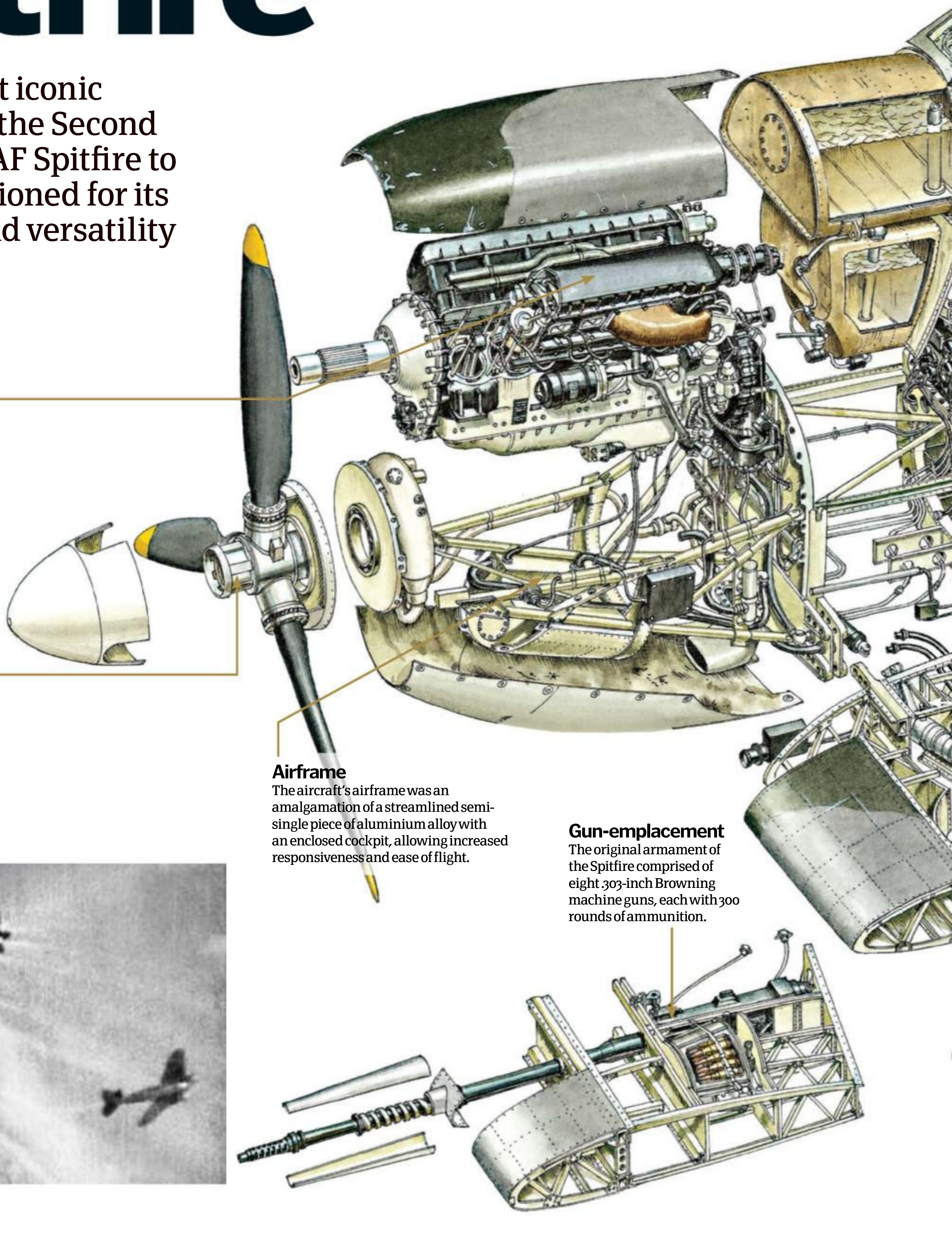
Max speed: Mach 2.04 (1,350mph)

Propulsion: 4x Rolls-Royce/ Snecma Olympus 593 engines

Ceiling: 60,000ft

Supermarine Spitfire

Arguably the most iconic fighter aircraft of the Second World War, the RAF Spitfire to this day is championed for its prowess, grace and versatility



Rolls-Royce Vee-12 engine
The Spitfire utilised two variant of Rolls-Royce engine during its production life span, the 27-litre Merlin and the 36.7-litre Griffon.

Propeller
Original Spitfires had wooden propellers, these were later replaced with variable-pitch propellers, and more blades were added as horsepower increased.

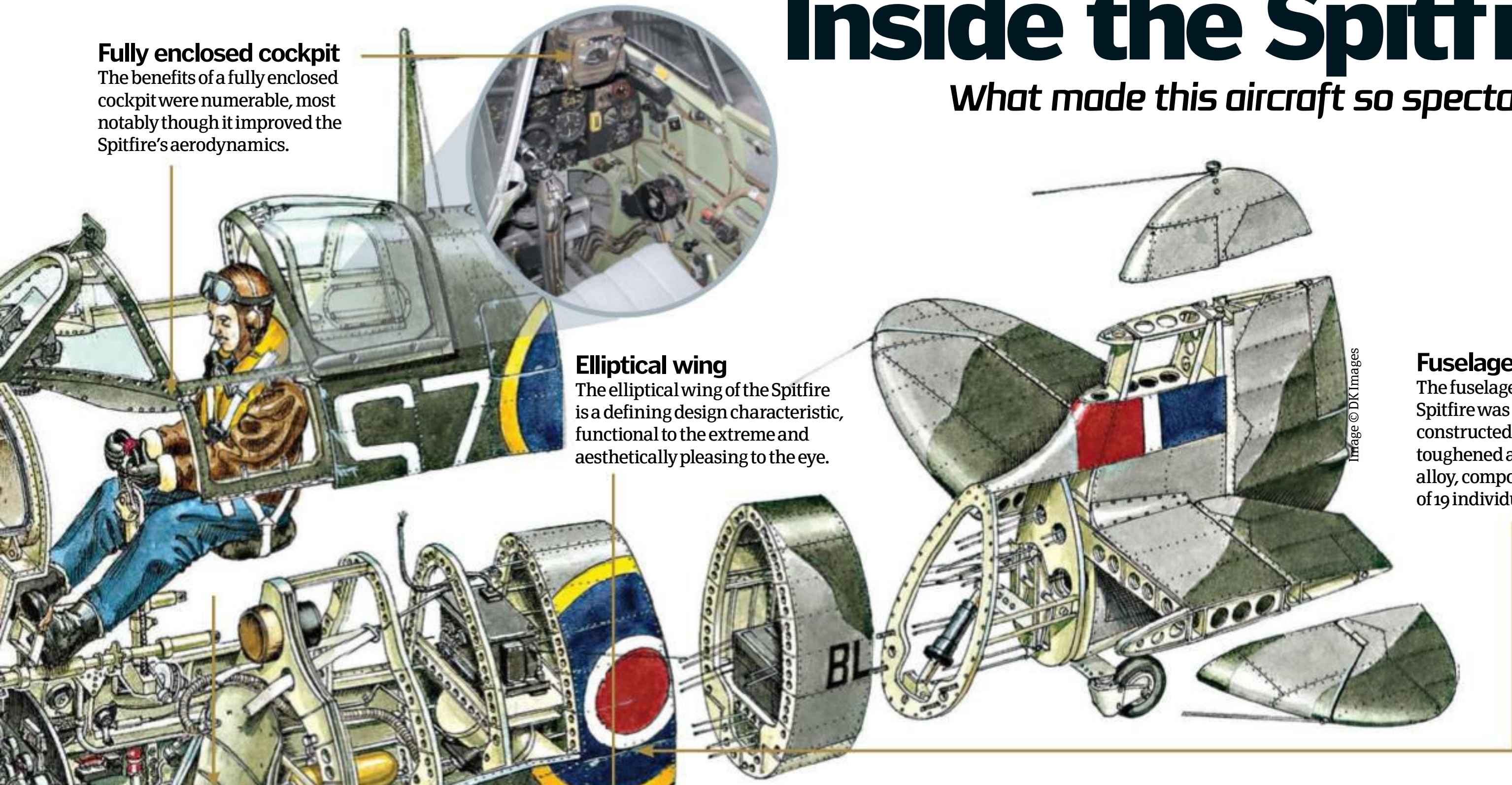
Airframe
The aircraft's airframe was an amalgamation of a streamlined semi-single piece of aluminium alloy with an enclosed cockpit, allowing increased responsiveness and ease of flight.

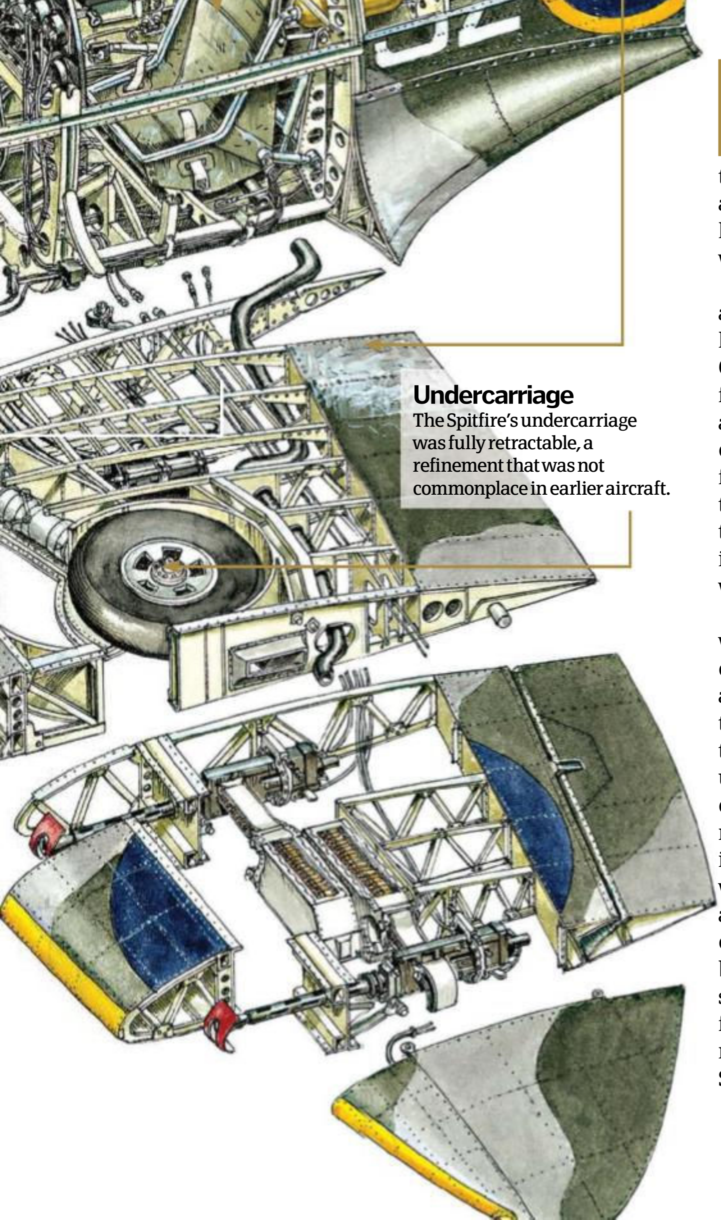
Gun-emplacement
The original armament of the Spitfire comprised of eight .303-inch Browning machine guns, each with 300 rounds of ammunition.

Video still from gun camera showing the tracers

Inside the Spitfire

What made this aircraft so spectacular?





Designed in the technologically fervent and innovatory melting pot of the Second World War, the Supermarine Spitfire became the fighter plane of the times. With its simple lines, elegant frame and superb aerodynamics, the Spitfire was to live on in the minds of generations during the war and for decades to come.

The Spitfire was the brainchild of aeronautical engineer Reginald Mitchell, who led a dedicated and talented team of designers. Originally planned as a short-range air-defence fighter, the Spitfire was built for speed and agility, traits that it was to need in the explosive dogfights it was to partake in as it met enemy fighters and bombers. Building a fighter plane, though, is more complex than listing desirable traits however, and the Spitfire's construction is a balletic series of compromises between weight, aerodynamics and firepower.

The frame of a spitfire with its elliptical wings is one of its most defining characteristics, casting a distinctive silhouette against the sky. The ellipse shaping was used to minimise drag while having the necessary thickness to accommodate the retracted undercarriages and the guns required for self defence. A simple compromise that had the resulting benefit of having an incredibly individual shape. In contrast, the airframe – which was influenced by exciting new advances in all metal, low-wing plane construction – was a complex and well-balanced amalgamation of a streamlined semi-single piece of aluminium alloy and a fully enclosed cockpit. This allowed unrivalled responsiveness and ease of flight, making the Spitfire a favourite for pilots.

Arguably, the other most defining and success-inducing element of the Spitfire was its engine, which took on the form of the Rolls-Royce Merlin and Griffon engines. Planned by a board of directors at Rolls-Royce who realised that their current Vee-12 engine was topping out at 700hp and that a more powerful variant would be needed, first the Merlin and later the Griffon engines were designed. The Merlin at first delivered 790hp, short of the 1,000hp goal set in its design brief, however this was to increase to 975hp in a few years. The Griffon then built upon the success of the Merlin, delivering at the climax of its advancement a whopping 2,035hp. These engines were to prove tantamount to the airframe and wing designs in the dominance of the Spitfire.

Despite its origins lying in short-range home defence, the Spitfire was to prove so versatile and successful that it was quickly adapted for a wide variety of military purposes. Many variants were created, including designs tailored for reconnaissance, bombing runs, high-altitude interception and general fighter-bomber operations. The most notable derivative, however, was the multi-variant Seafire, specially designed for operation on aircraft carriers with the added ability to double-fold its wings for ease of storage.

Considering the place in history that the Spitfire holds – a fighter-bomber aircraft that bridged the gap between the age of the propeller engine to that of the jet – the fact that they are still collected (with an average cost of £1.4 million) and flown today is unsurprising. The Spitfire is a timeless piece of engineering that shows some of the most creative and advanced efforts in military history.

Lancaster

Famed for its prowess and entrenched in popular culture by *The Dam Busters* of 1955, the Lancaster bomber played a vital role in securing an allied victory in World War II

Arguably the most famous heavy bomber of World War II, the Avro-built Lancaster bomber undertook some of the most dangerous and complex missions yet encountered by the RAF. Primarily a night bomber but frequently used during the day too, the Lancasters under Bomber Command flew some 156,000 sorties during the war, dropping 609,000 tons of bombs. Among these bombs was the famous 'bouncing bomb' designed by British inventor Barnes Wallis, a payload that would lead the Lancaster to remain famed long after 1945. We take a look inside a Avro Lancaster to see what made it so successful.

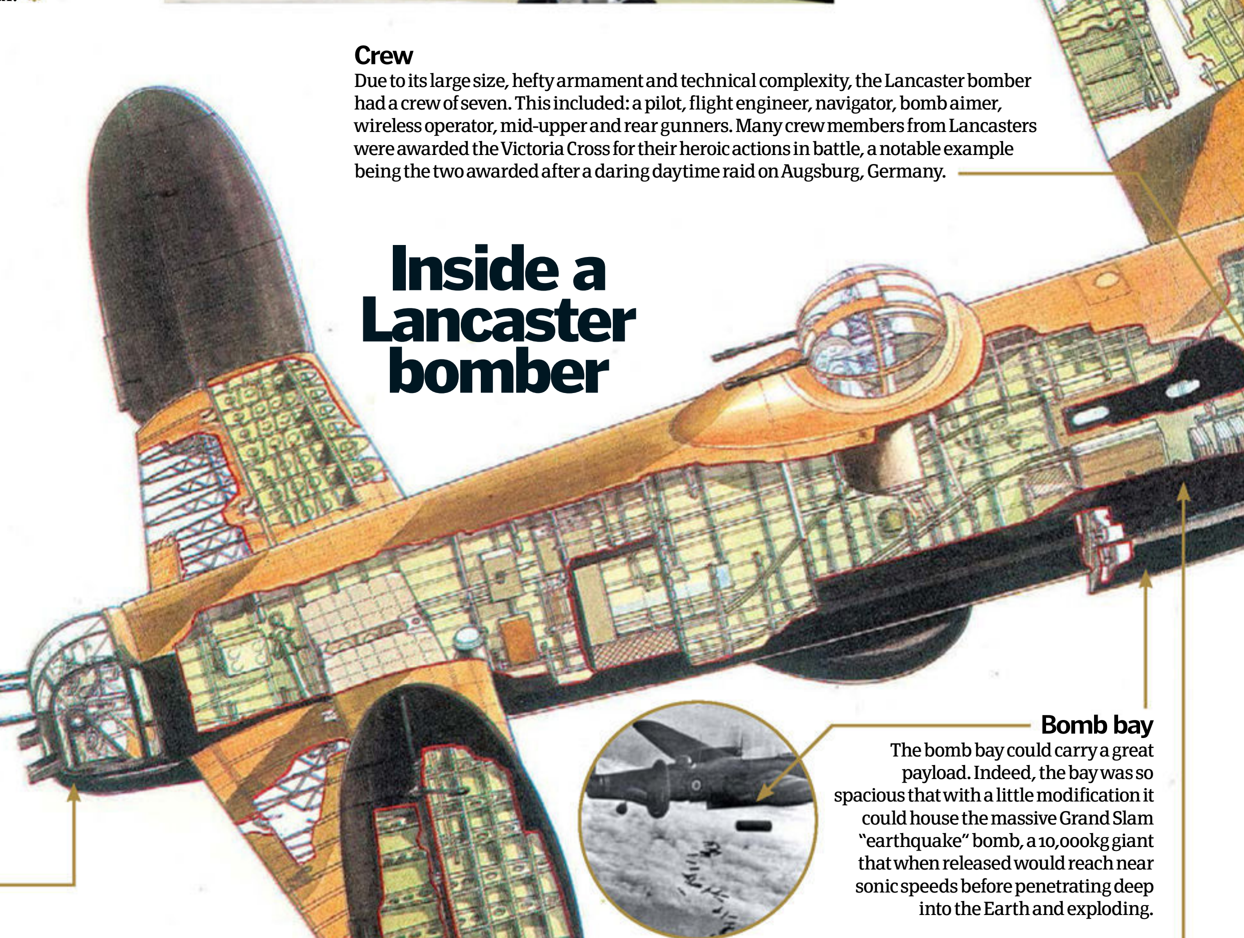
Lancaster bombers dropped 609,000 tons of bombs

The statistics...

Lancaster bomber

Crew: 7
Length: 21.18m
Wingspan: 31.09m
Height: 5.97m
Weight: 29,000kg
Powerplant: 4 x Rolls-Royce Merlin XX V12 engines
Max speed: 280mph
Max range: 3,000 miles
Max altitude: 8,160m
Armament: 8 x .7.7mm Browning machine guns; bomb load of 6,300kg

Inside a Lancaster bomber



Crew

Due to its large size, hefty armament and technical complexity, the Lancaster bomber had a crew of seven. This included: a pilot, flight engineer, navigator, bomb aimer, wireless operator, mid-upper and rear gunners. Many crew members from Lancasters were awarded the Victoria Cross for their heroic actions in battle, a notable example being the two awarded after a daring daytime raid on Augsburg, Germany.

Turrets

As standard the Lancaster bomber was fitted with three twin 7.7mm turrets in the nose, rear and upper-middle fuselage. In some later variants of the Lancaster the twin 7.7mm machine guns were replaced with 12.7mm models, which delivered more power. The rear and upper-middle turrets were staffed permanently by dedicated gunners, while the nose turret was staffed periodically by the bomb aimer when caught up in a dogfight.

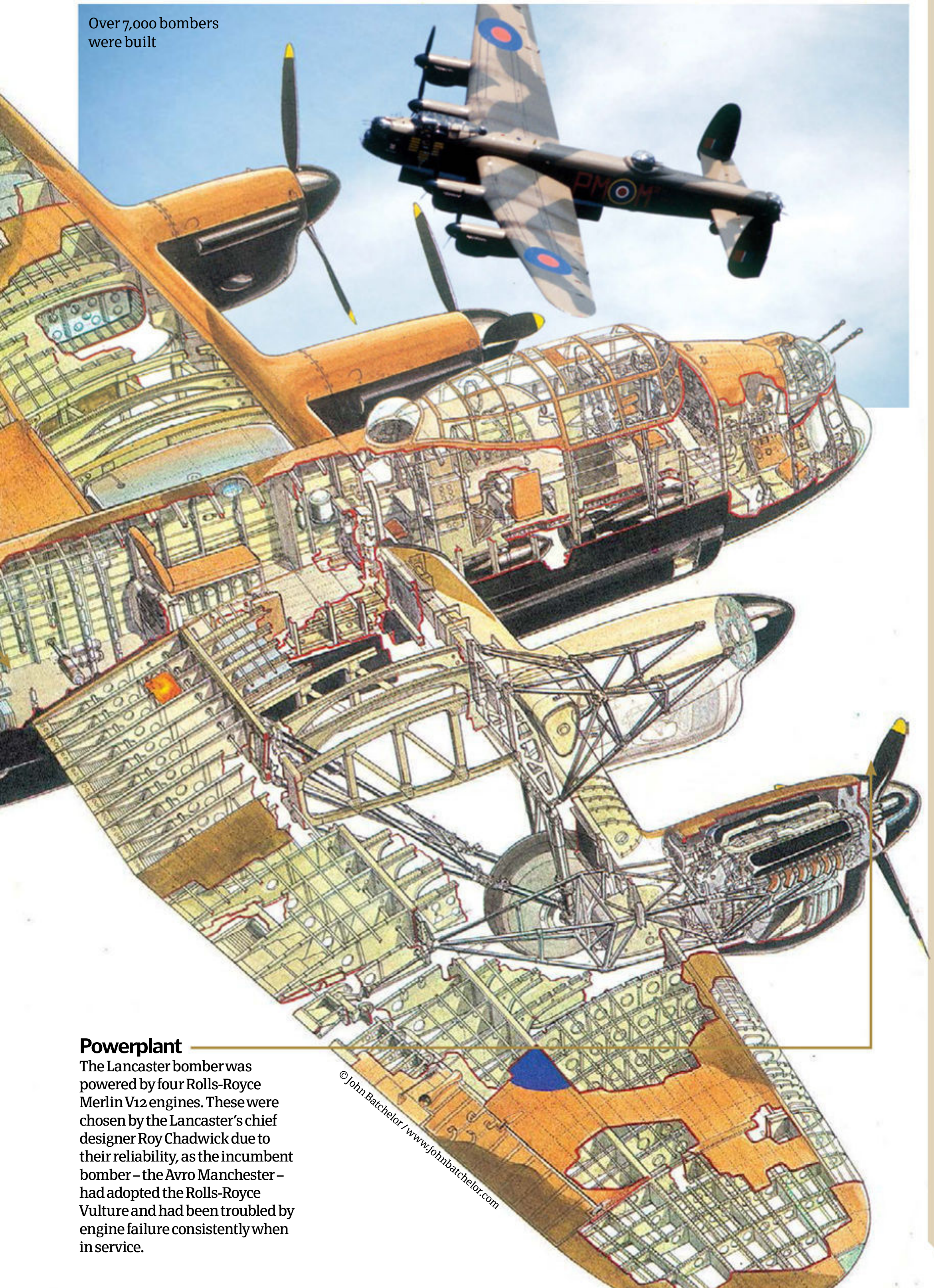
Bomb bay

The bomb bay could carry a great payload. Indeed, the bay was so spacious that with a little modification it could house the massive Grand Slam "earthquake" bomb, a 10,000kg giant that when released would reach near sonic speeds before penetrating deep into the Earth and exploding.

Fuselage

The Lancaster was designed out of the earlier Avro Type 683 Manchester III bomber, which sported a three-finned tail layout and was similar in construction. While the overall build remained similar the tri-fin was removed in favour of a twin-finned set up instead. This is famously one of only a small number of design alterations made to the bomber, which was deemed to be just right after its test flights.

bomber



Over 7,000 bombers were built

© John Batchelor / www.johnbatchelor.com

Powerplant

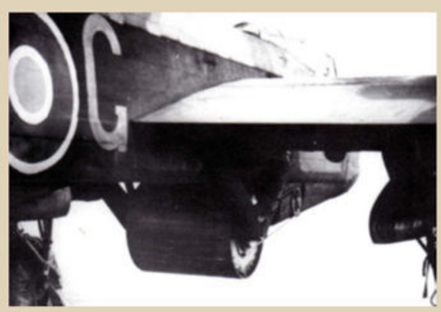
The Lancaster bomber was powered by four Rolls-Royce Merlin V12 engines. These were chosen by the Lancaster's chief designer Roy Chadwick due to their reliability, as the incumbent bomber – the Avro Manchester – had adopted the Rolls-Royce Vulture and had been troubled by engine failure consistently when in service.

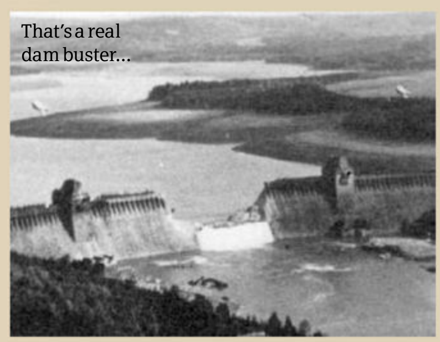
© Bluemoose

The bouncing bomb

One of the most famous parts of the Lancaster's heritage is its role in carrying and releasing the 'bouncing bomb' payload, as glamorised in the 1955 film *The Dam Busters*. The bomb was designed by Barnes Wallis – who was also the creator of the Grand Slam and Tallboy bombs – and was special in its ability to bounce along the top of a surface of water, much akin to skimming a stone. It was designed to counteract and evade German defences below and above the waterline, allowing Allied forces to target German hydroelectric dams and floating vessels.

In May 1943 the bouncing bombs were utilised in Operation Chastise, an allied mission to destroy German dams in the Ruhr Valley. The aircraft used were modified Avro Lancaster Mk IIIs, which had much of their armour and central turret removed in order to accommodate the payload. Despite eight of the Lancasters being lost during the operation, as well as the lives of 53 crew, a small number of bouncing bombs were released and they caused two dams to be breached, one to be heavily damaged and 1,296 civilians to be killed.



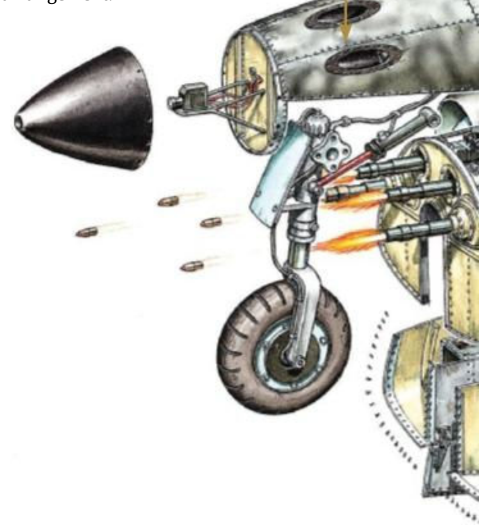


That's a real dam buster…

Messerschmitt Me 262

How this German fighter aircraft brought terrifying speed and combative dominance to the aerial battlefields of World War II

The Messerschmitt Me 262 Schwalbe, as seen in this photograph, was the first variant of the jet to fall into Allied hands



Speed kills. This is a fact of war that the Nazi regime understood well, employing it to great effect with their 'Blitzkrieg' (lightning war) tactics of WWII, puncturing holes in Allied lines with great speed and firepower. It was a mantra they incorporated into all aspects of their military and, as shown in the groundbreaking Messerschmitt Me 262 fighter jet, often generated spectacular results.

The Me 262 was the most advanced aviation design brought to fruition during World War II, and the first ever operational jet-powered fighter aircraft in the world. It featured a state-of-the-art, streamlined steel and aluminium alloy chassis, twin super-powerful Junkers Jumo 004 B-1 turbojet engines and a suite of weaponry that allowed it to fulfil a wide variety of roles. It was originally conceived to be a high-speed fighter-interceptor used to take down Allied bombers during sorties (flight missions), however under order from Adolf Hitler himself, its role was widened to also include bombing duties.

Its aerial dominance rested on its high top speed of 900km/h (560 mph), which obliterated its nearest rivals, the American P-51 Mustang and British Spitfire. Indeed, the extreme velocity that the Me 262 brought to the aerial battlefield meant that traditional dog-fighting tactics needed to be rewritten, with Allied pilots unable to track the aircraft with their electric gun turrets or tail them over long stretches. Instead, Allied pilots had to gang up and attempt to force the 262's pilot into making low-speed manoeuvres, from which it could be shot down.

This formidable power came from the turbojets. They didn't provide as much thrust at lower speeds than that of propellers, meaning that Me 262s took longer to reach high speed. However, once flying, the aircraft could easily outpace any Allied plane. Further, the turbojets granted the Me 262 a higher rate of climb than its contemporaries, which, when used tactically, allowed them to out-position the enemy and line up attack runs on lower-flying bombers. Air-to-air damage was delivered with four 30mm MK 108 cannons, as well as 24 55mm R4M rockets. The Me 262's cannons allowed for short-range firing runs, while the unguided R4M rockets allowed larger targets to be peppered with high-explosive munitions, each one capable of totally destroying any aircraft of the day. Air-to-ground attacks were actualised through a selection of 250kg or 500kg (550lb to 1,100lb) free-fall bombs, which were stored and released from dedicated bomb bays. Through its weaponry and intense speed, the Me 262 racked up a reported five-to-one kill rate, shooting down a variety of different Allied aircraft.

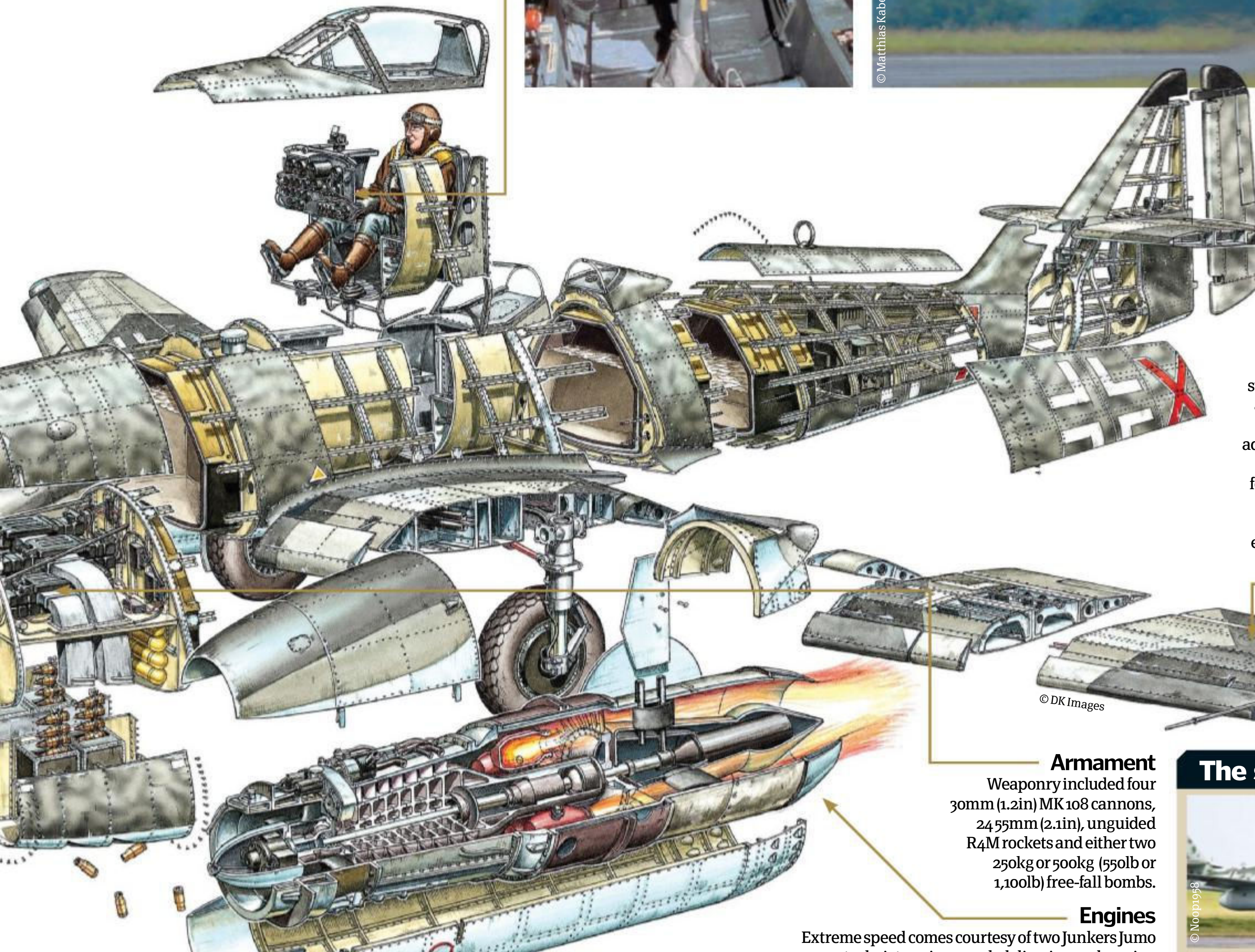
Unfortunately, the reign of the Me 262 was short-lived, as mass delays in bringing it to operational functionality meant that it was not introduced until the spring of 1944, just over a year before the close of the war. Further, poor parts availability and dissemination of maintenance information to mechanics led to serious deficiencies

The Me 262's engines allowed a top speed of 900km/h

© Matthias Kabel

Instrumentation

Flight instruments in the Me 262's cockpit included an artificial horizon, bank and turn indicators, airspeed indicator, altimeter, rate of climb indicator, repeater compass and blind approach indicator.



© DK Images

Wings

The Me 262 sported a swept-wing profile, with a leading edge sweep of 18.5°. This sweep was added to the aircraft – the original design did not feature swept wings – as the Jumo 004 engines proved heavier than expected and the centre of lift needed to be repositioned.

Armament

Weaponry included four 30mm (1.2in) MK 108 cannons, 24 55mm (2.1in), unguided R4M rockets and either two 250kg or 500kg (550lb or 1,100lb) free-fall bombs.

Engines

Extreme speed comes courtesy of two Junkers Jumo 004 turbojet engines, each delivering a whopping 900kgf (1,980lbf). This gave the fighter a top speed of 900km/h (560mph), over 160km/h (100mph) more than its nearest competitor.

in fleet fly time, with few aircraft in the air at any one time. Due to its aerial dominance, Allied forces soon identified the Me 262's potential threat and dedicated large quantities of bombing sorties to destroying construction factories and launch bases.

"The Me 262 was the most advanced aviation design brought to fruition during World War II"

The statistics…

© Noop1958

Me 262 A-1a

Crew: 1

Length: 10.6m (34.8ft)

Wingspan: 12.6m (41.5ft)

Height: 3.5m (11.5ft)

Weight: 3,795kg (8,367lb)

Powerplant: 2 x Junkers Jumo 004 B-1 turbojet engines (1,980lbf each)

Max speed: 900km/h (559mph)

Range: 1,050km (652mi)

Max altitude: 11,450m (37,566ft)

Armament: 4 x 30mm MK 108 cannons, 24 x 55mm R4M rockets, 2 x 250kg bombs

F-86 Sabre

Considered the foremost military aircraft of the Fifties, the F-86 Sabre was a highly versatile fighter jet as fast as it was lethal

The F-86 Sabre was a highly successful single-seat fighter jet built by North American Aviation (now part of Boeing) in the late-Forties. The aircraft – the first western jet to feature swept wings, as well as one of the first capable of breaking the sound barrier in a dive – saw action throughout the Korean War and Cold War, and has become a highy recognisable icon in aircraft engineering history.

Built initially to combat the Russian MiG-15, the Sabre was geared towards flight superiority roles, dispatched to undertake furious high-speed dogfights. Though inferior to the Russian jet in terms of lightness and weaponry, the reduced transonic drag delivered by the swept wings – combined with its streamlined fuselage and advanced electronics – granted it far superior handling. This ability to outmanoeuvre the MiG-15 saw it establish supremacy in combat.

Despite overall armament inferiority to its rivals, the Sabre was one of the first military jets capable of firing guided air-to-air missiles and later variants, such as the F-86E, were fitted with radar and targeting systems that were revolutionary for the time. These factors, along with its high service ceiling (ie maximum altitude) and its generous range of around 1,600 kilometres (1,000 miles), therefore enabled it to intercept any enemy aircraft with ease.

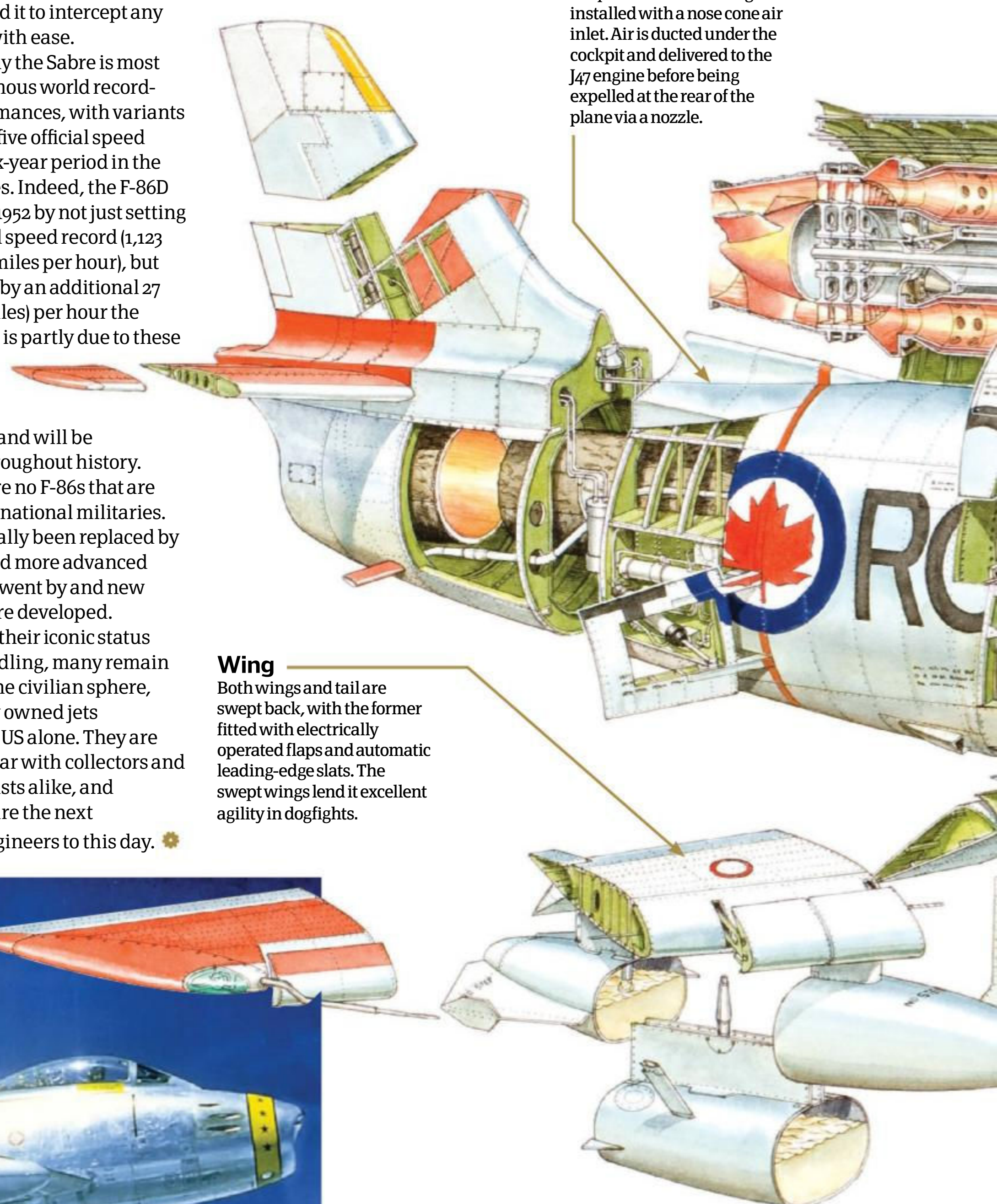
However, today the Sabre is most known for its famous world record-breaking performances, with variants of the jet setting five official speed records over a six-year period in the Forties and Fifties. Indeed, the F-86D made history in 1952 by not just setting the overall world speed record (1,123 kilometres/698 miles per hour), but then bettering it by an additional 27 kilometres (17 miles) per hour the following year. It is partly due to these records that the F-86 remains to be a beloved aircraft and will be remembered throughout history.

Today there are no F-86s that are still in service in national militaries. They have naturally been replaced by more modern and more advanced aircrafts as time went by and new technologies were developed. However, due to their iconic status and reliable handling, many remain in operation in the civilian sphere, with 50 privately owned jets registered in the US alone. They are extremely popular with collectors and aircraft enthusiasts alike, and continue to inspire the next generation of engineers to this day.

Although built in North America at least 20 other countries used Sabres in their air forces, including Japan, Spain and the UK

On board the F-86E

Explore the advanced engineering that makes the Sabre such a formidable fighter jet...



Fuselage

A tapered conical fuselage is installed with a nose cone air inlet. Air is ducted under the cockpit and delivered to the J47 engine before being expelled at the rear of the plane via a nozzle.

Wing

Both wings and tail are swept back, with the former fitted with electrically operated flaps and automatic leading-edge slats. The swept wings lend it excellent agility in dogfights.

Engine
The F-86E uses a GE J47-13 turbojet engine capable of outputting 2,358kgf (5,200lbf) of thrust. This raw power grants it a top horizontal speed of about 1,050km per hour (650mph).

Cockpit
The F-86E is fitted with a small bubble canopy cockpit that covers a single-seat cabin for the pilot. The cockpit is in a very forward position, tucked just behind the nose cone.

The statistics...

F-86E Sabre

Length: 11.3m (37ft)

Wingspan: 11.3m (37ft)

Height: 4.3m (14ft)

Max speed: 1,046km/h (650mph)

Range: 1,611km (1,001mi)

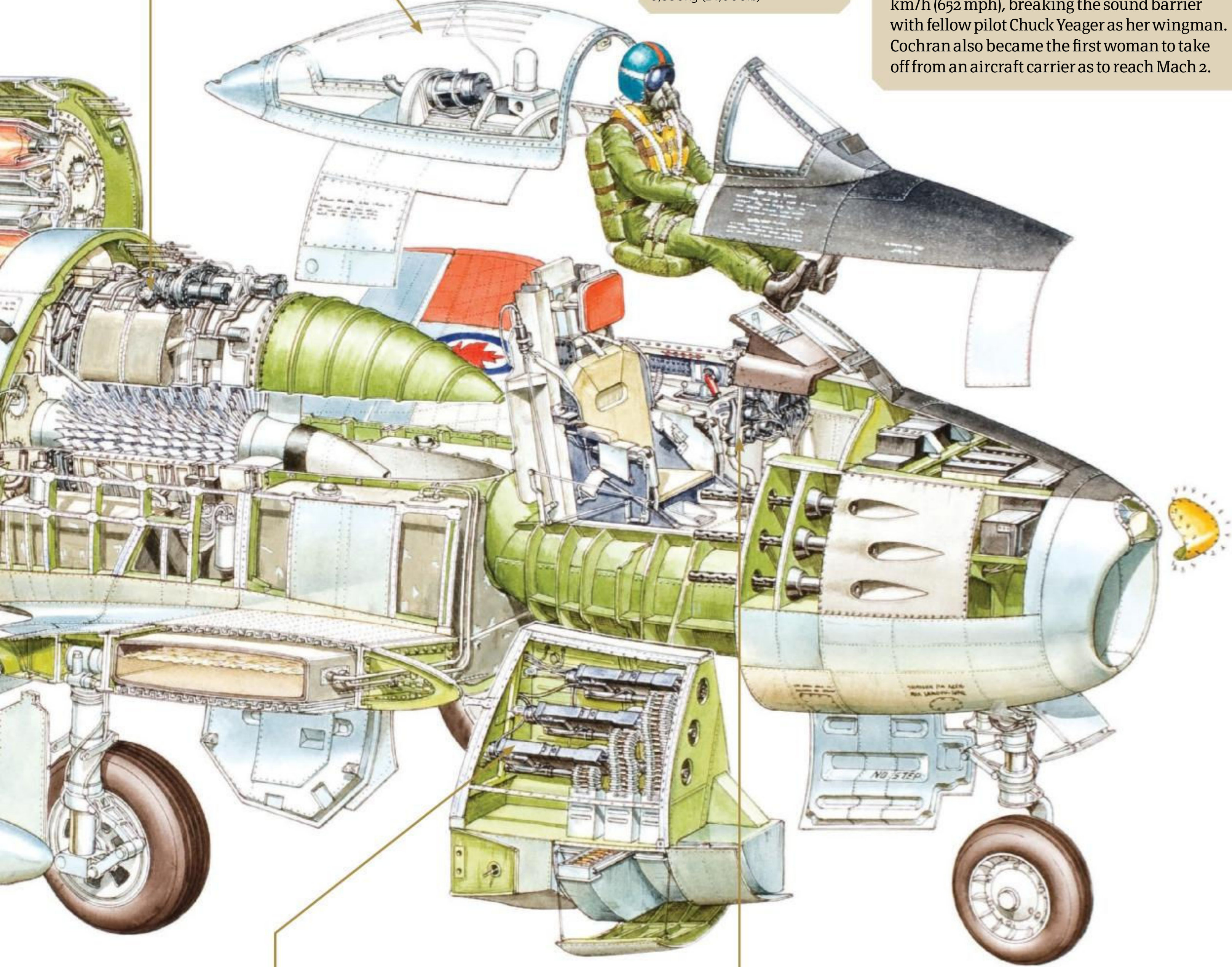
Max altitude: 1,371m (45,000ft)

Combat weight: 6,350kg (14,000lb)

Who was high flyer Jacqueline Cochran?

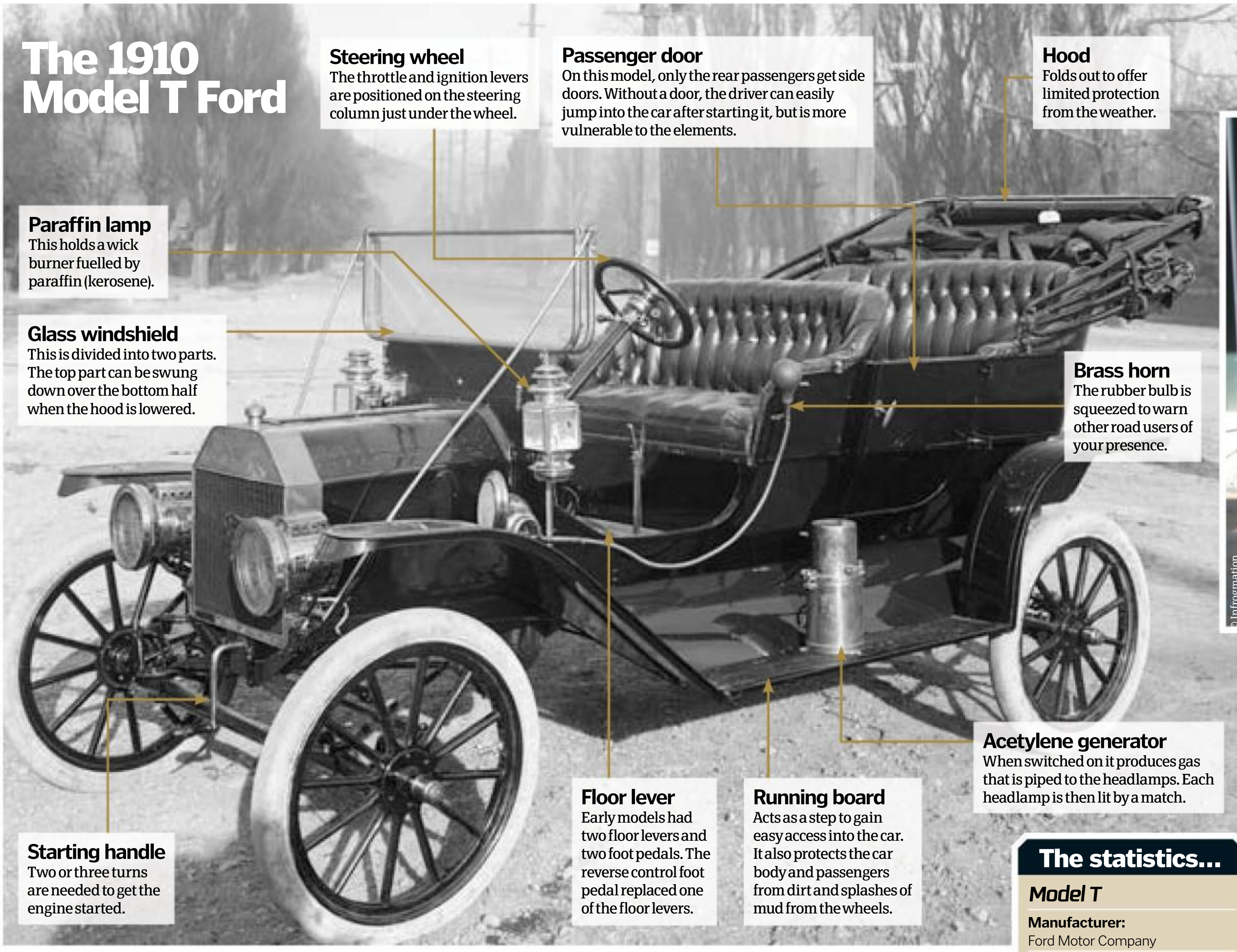
Born in 1906, Cochran was a pioneering American aviator and one of the most gifted pilots of her generation. This led her to become the first woman in the world to break the sound barrier – an amazing feat which she performed in a custom, one-off F-86 Sabre.

The record was broken on 18 May 1953 at Rogers Dry Lake in California. In her F-86, Cochran racked up an average speed of 1,050 km/h (652 mph), breaking the sound barrier with fellow pilot Chuck Yeager as her wingman. Cochran also became the first woman to take off from an aircraft carrier as to reach Mach 2.



Weaponry
The Sabre is equipped with six .50-caliber (12.7mm) M2 Browning machine guns and 16 127mm (5in) HVAR rockets, as well as a variety of freefall bombs as well as unguided missiles.

Electronics
An A-1CM gun sight in partnership with an AN/APG-30 radar system makes the F-86E one of the most technologically advanced jets of its time. The radar can quickly work out the range to potential targets.



The statistics...

Model T

Manufacturer: Ford Motor Company
Year introduced: 1908
Dimensions: Length: 2,540mm, width: 1,422mm, height: 2,387mm
Engine: 2896cc
Top speed: 45mph
Horse power: 22.5
Required fuel: Petrol
Unit price: $850

The Model T

The car that brought motoring to the masses

Early Model T styles included this popular open-top touring car

By today's standards, Henry Ford's Model T has many unusual characteristics. Before you can jump into the driver's seat, you have to turn a hand crank at the front of the car to start it. This is a hazardous process as the hand crank can break your thumb if the engine backfires, and if the throttle lever on the steering column is not set properly it will run you over as soon as it starts. Fortunately, an optional electric starter was introduced in 1919.

The Model T has three foot pedals and a floor lever. To drive off, you increase the throttle lever, move the floor lever forwards from its neutral position and depress the clutch foot pedal on the left. As you pick up speed, you can move from first to second gear by releasing pressure on the clutch pedal. To stop, drivers would simply have to reduce the throttle, press down the clutch pedal, depress the brake foot pedal on the right and put the floor lever into neutral. To go backwards you keep the floor lever in neutral and press down the middle reverse foot pedal.

Early versions of the car had brass acetylene lamps, and its ten-gallon fuel tank was mounted under the front seat. As this fed petrol to the carburettor using gravity, the Model T could not climb steep hills if the tank was low on fuel. The solution to this was to drive up hill in reverse.

Its engine is front mounted, and features four cylinders in one en bloc casting. This simple engine is relatively


Just as its modern counterparts developed different styles and shapes over the years, so too did the Model T

ON THE MAP

Model T production centres

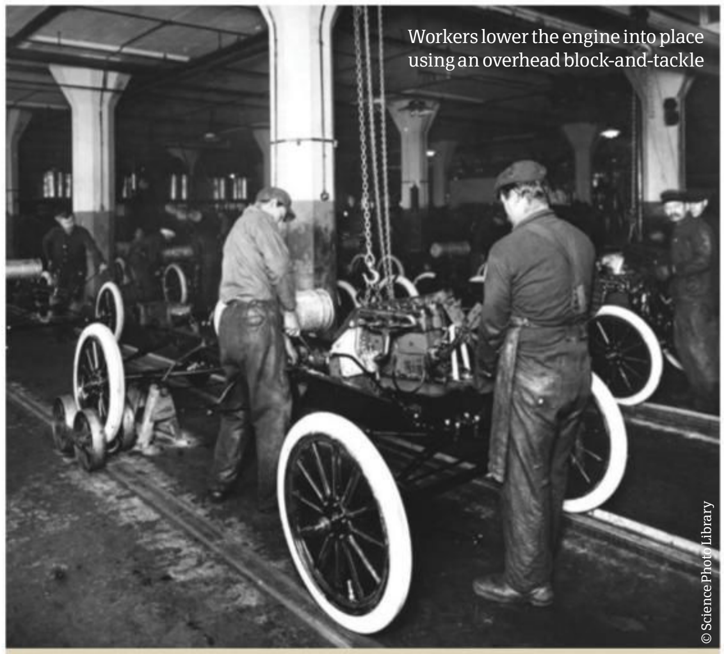
1. Highland Park Plant, Michigan
2. Trafford Park, Manchester, UK
3. Walkerville, Ontario, Canada
4. La Boca, Buenos Aires, Argentina
5. Geelong, Victoria, Australia
6. Berlin, Germany

The Model T was a welcome addition to police forces

© Harry L Sneider

easy to run and maintain. The first models were runabouts with open bodies and a hood that can be folded down. Lots of different car and truck bodies were later fitted to the Model T chassis by Ford and other companies.

Since the Model T was equally at home in town or as an off-road farm workhorse, and available at the cheapest price possible, it quickly dominated the USA and made motoring an essential part of our lives.


Workers lower the engine into place using an overhead block-and-tackle

© Science Photo Library

Mass production

The revolutionary methods used by Ford opened up a world of possibilities

Mass production using a moving assembly line was the key innovation that made the Model T so successful. Car production had been largely pitched at the luxury market with hand-built bespoke models being the norm. Henry Leland, who worked for Cadillac, pioneered the standardisation of car components, and moving production lines were used in Chicago slaughterhouses. The genius of Ford was to integrate these methods and reduce the production of the Model T to 84 key areas.

The chassis of the car was run along a track and each worker carried out a very simple and repetitive production task, before it was moved on to the next work area. The engine and other components were made in a similar manner before being added to the chassis. This slavish process made it possible to reduce the time to make one Model T from 12 hours eight minutes to 93 minutes.

As early as 1914, Ford's mass production techniques produced 300,000 cars with 13,000 workers compared to the 66,350 workers at all the other car companies who only produced 280,000 cars.

From 27 September 1908 till the end of production on 26 May 1927, 15 million Model Ts were made. The Model T met and exceeded Henry Ford's vision of creating a simply designed car using the best materials at a price affordable to everyone.


Connecting the barrel-shaped petrol tank

© Science Photo Library

The Flying Scotsman locomotive

Inside the film star, record-breaker and national treasure


The original 4472 A1 locomotive was designed by Sir Herbert Nigel Gresley

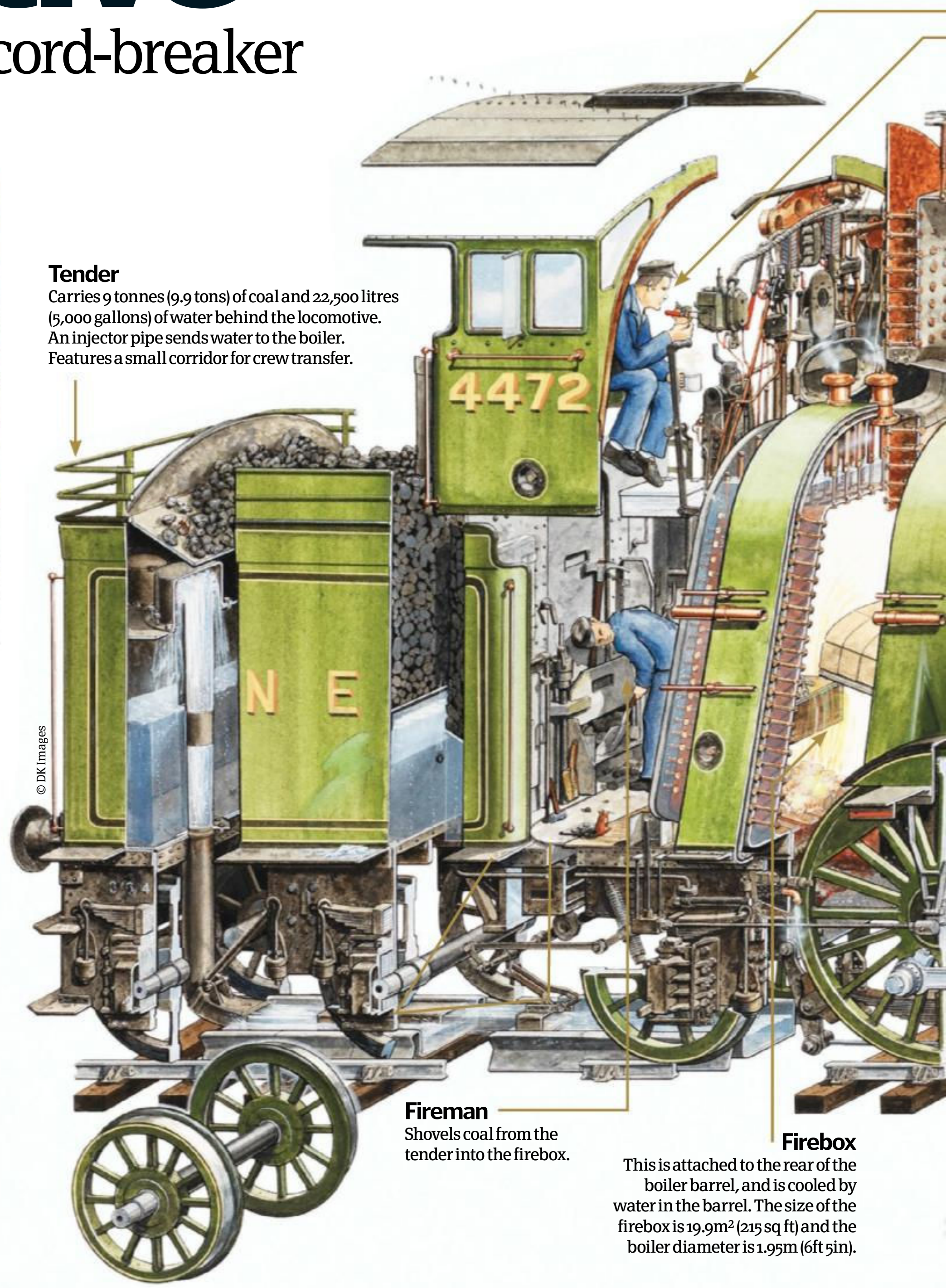
The Flying Scotsman began life as No 1472, an A1 Pacific-class locomotive. The Pacific class had a 2-6-2 arrangement of wheels, which enabled it to carry a bigger boiler, making it suitable for long-distance passenger services. Under ownership of the London and North Eastern Railway Company (LNER) it was renumbered the 4472 and christened the Flying Scotsman.

When it broke down and was taken out of regular service it was the ideal candidate for putting on show at the British Empire Exhibition in 1924 and 1925. It was an immediate hit with the public, and its fame was sealed when in 1928 it launched the regular 10am non-stop Flying Scotsman Express Service from King's Cross, London, to Waverley, Edinburgh.

To cope with the 631km (392-mile) route the locomotive pulled a special eight-wheel tender that carried great quantities of water and coal. Since the crew had to be replaced during the eight-hour journey without stopping, a special corridor was built in the tender to allow the relief crew to pass between the train and the cab.

The Flying Scotsman became even more famous on 30 November 1934, when it travelled at 160.9km/h (100mph) breaking the world speed record.

In January 1947, the Flying Scotsman was converted to the A3 class that incorporated a larger boiler with a higher boiler pressure and, a year later, it was re-designated as the No 60103 under the ownership of British Rail. In 1963, it was sold off and went through several owners before being rescued by the National Railway Museum, York, in May 2004.



Tender
Carries 9 tonnes (9.9 tons) of coal and 22,500 litres (5,000 gallons) of water behind the locomotive. An injector pipe sends water to the boiler. Features a small corridor for crew transfer.

Fireman
Shovels coal from the tender into the firebox.

Firebox
This is attached to the rear of the boiler barrel, and is cooled by water in the barrel. The size of the firebox is 19.9m² (215 sq ft) and the boiler diameter is 1.95m (6ft 5in).

The Flying Scotsman Express Service

JUNE 1862

Service begins
The East Coast mainline from London to Edinburgh is used to run the first Special Scotch Express, departing at 10am with a journey time of ten and a half hours.

1888

Faster
Rivalry between rail companies brought the journey time to as low as seven and a half hours. As this racing was dangerous it is agreed to set the time at eight hours 15 minutes.

Streamlining
Since the engine was so tall, the cab, dome and chimney had to be virtually flush with the boiler to avoid hitting bridges between Newcastle and Edinburgh.

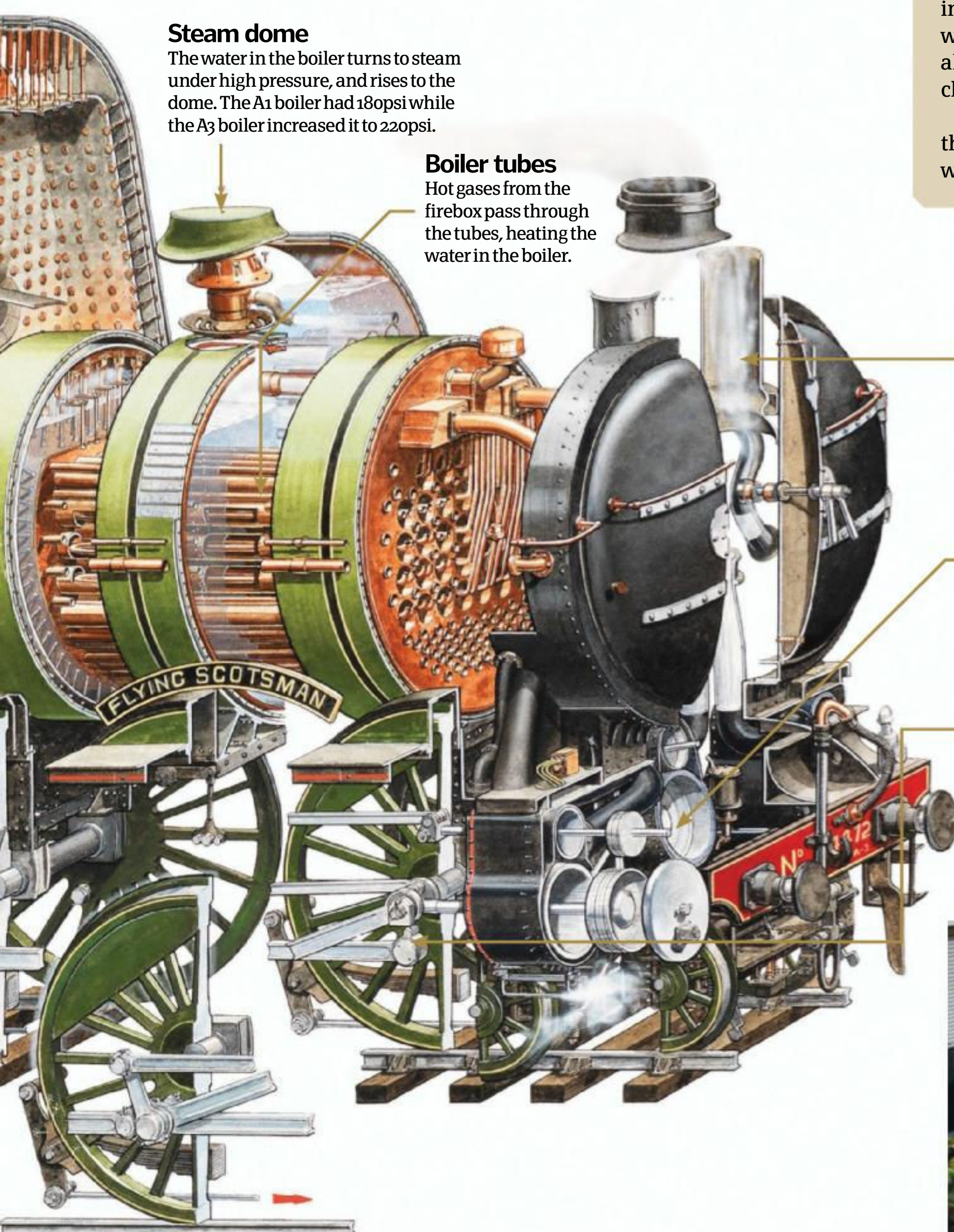
Driver
The driver uses the throttle to control the regulator in the steam dome to increase or decrease the amount of steam sent to the cylinders.


© David Ingham

The Flying Scotsman was not only known for speed but luxury too

Steam dome
The water in the boiler turns to steam under high pressure, and rises to the dome. The A1 boiler had 180psi while the A3 boiler increased it to 220psi.

Boiler tubes
Hot gases from the firebox pass through the tubes, heating the water in the boiler.



Chimney
In 1958, the Scotsman was fitted with a Kylchap exhaust system that evenly mixed the steam from the pistons and gases from the boiler tubes to improve performance.

Cylinders
The Scotsman has three cylinders on each side. A Gresley-conjugated valve gear system orders the operation of the pistons inside the cylinders.

Cranks and connecting rods
The movement of the pistons is transferred through these rods to the wheels. The diameter of the wheels is 0.96m (3ft 2in) for the first four, 2.03m (6ft 8in) for the coupled set and for the trailing wheels 1.12m (3ft 8in).

Sir Nigel Gresley and the LNER

Herbert Nigel Gresley (19 June 1876-5 April 1941) served his apprenticeship at Crewe Locomotive Works. His leadership and engineering skills led him to become the chief mechanical engineer of the London and North Eastern Railway Company (LNER) based in Doncaster.

He designed the A1, and upgraded them to the A3 class. In 1935, he introduced the A4 class that included the Mallard, which gained the world speed record by travelling at 202.7km/h (126mph) in 1938. He also worked on steering gear for ships and, in total, designed 27 classes of steam locomotive.

Gresley was always eager to test new innovations and incorporate the best ideas from Europe and America into his designs. In 1936 he was knighted by King Edward VIII in recognition of his industry.

The statistics...

The Flying Scotsman

Designer: Sir Herbert Nigel Gresley

Manufacturer: Doncaster Railway Works

Year built: 1923

Class: A3

Length: 21.6m (70ft)

Width: 2.8m (9ft 3in)

Height: 4m (13ft)

Weight: 97.5 tonnes (107 tons)

Boiler pressure: 220psi

Top commercial speed: 108km/h (67mph)

Top record speed: 160.9km/h (100mph)

Status: Owned by the National Railway Museum, York

The London and North Eastern Railway Company is to thank for the Scotsman name

1900

Luxury
Passenger comfort is enhanced by the introduction of dining cars, heating and corridors linking carriages.

1924

Official recognition
This service had been nicknamed the Flying Scotsman since the 1870s. LNER now officially gives the service this name and gives the 4472 locomotive the same title.

1932

Speeding
The restricted journey time of eight hours 15 minutes was officially reduced to seven and a half hours.

23 MAY 2011

A new beginning
The Class 91, electric locomotive 91101 starts an Edinburgh to London weekday service. It takes just four hours to run the route.

The Mayflower

Discover what life was like on board the ship that took the Pilgrim Fathers to America

The Mayflower is one of the most famous ships associated with English maritime history. After transporting the Pilgrim Fathers to a new life in America during 1620, the Mayflower was often regarded as a symbol of religious freedom in the United States.

Originally, however, the Mayflower was a simple cargo ship that was used for the transportation of mundane goods – namely timber, clothing and wine. While statistical details of the ship have been lost, when scholars look at other merchant ships of this period they estimate that it may have weighed up to 182,000 kilograms. It is suggested that the ship would have been around seven metres wide and 30 metres in length.

The ship's crew lived on the upper decks. All in all, 26 men are believed to have manned the Mayflower on her legendary journey. The Master or Commander was a man called Christopher Jones: he occupied the quarters situated at the stern of the ship. The regular crew lived in a room called the forecastle, which was found in the bow – accommodation was cramped, unhygienic and highly uncomfortable. It was constantly drenched by sea water and the officers on board were fortunate in that they had their accommodation in the middle of the ship.

During the historic voyage, the Mayflower carried 102 men, women and children – these Pilgrims were boarded in the cargo area of the ship, which was deep below deck where the living conditions led to seasickness and disease. The Mayflower set sail from England in the July of 1620, but the ship was forced to turn back twice because a vessel that accompanied it began to leak water. Many problems affected the Mayflower and her crew during the voyage. There were serious threats from pirates, but it was storm damage that was to prove problematic on this journey. In the middle part of the expedition, severe weather caused damage to the wooden beam that supported the ship's frame. Fortunately, however, it was repairable.

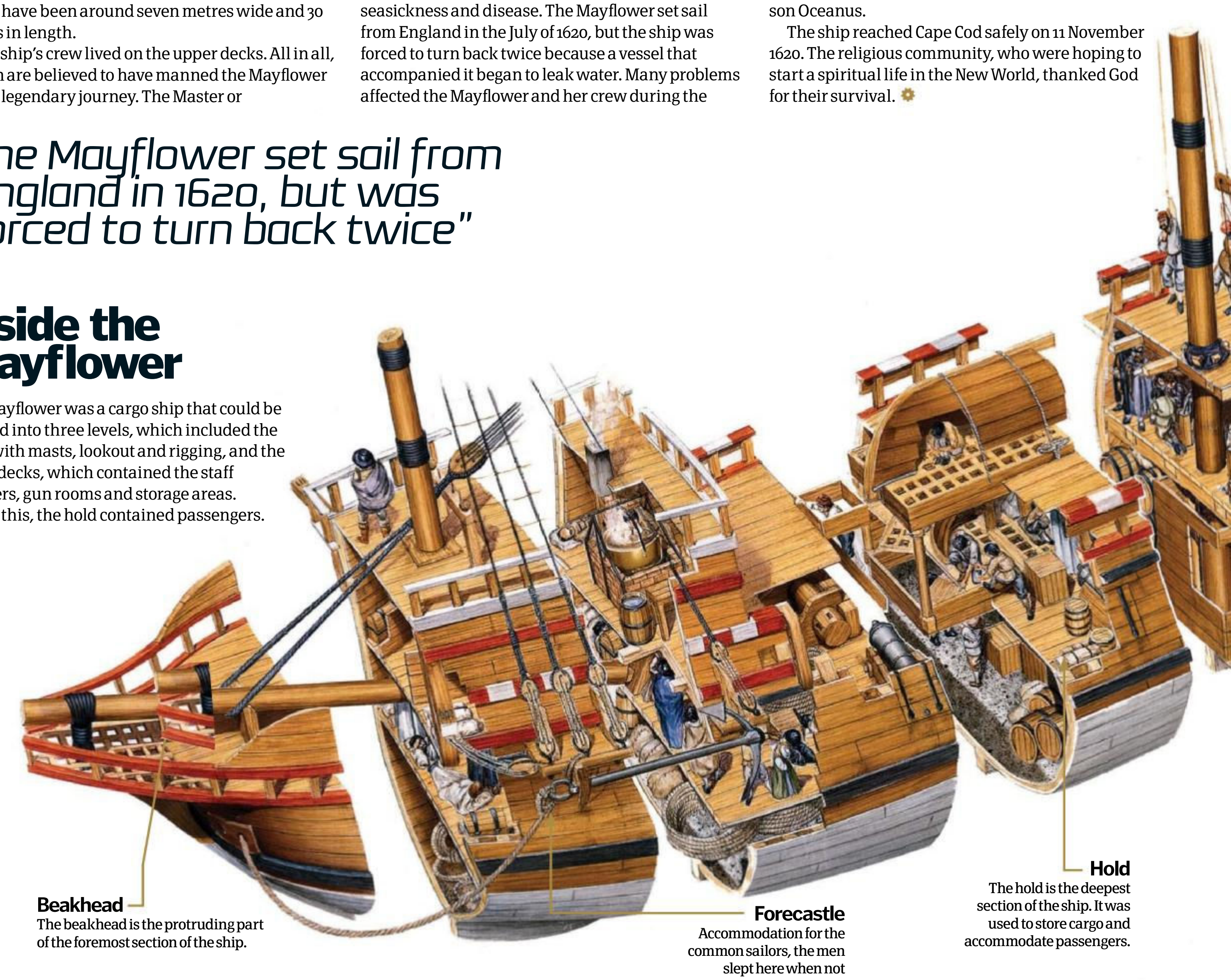
Several accidents also occurred, including the near drowning of John Howland who was swept overboard but then rescued. Less fortunate was a crew member who died unexpectedly – considered by all as 'mean spirited' – his demise was viewed as a punishment from God. A child was also born during the voyage: Elizabeth Hopkins called her son Oceanus.

The ship reached Cape Cod safely on 11 November 1620. The religious community, who were hoping to start a spiritual life in the New World, thanked God for their survival.

"The Mayflower set sail from England in 1620, but was forced to turn back twice"

Inside the Mayflower

The Mayflower was a cargo ship that could be divided into three levels, which included the deck with masts, lookout and rigging, and the lower decks, which contained the staff quarters, gun rooms and storage areas. Below this, the hold contained passengers.

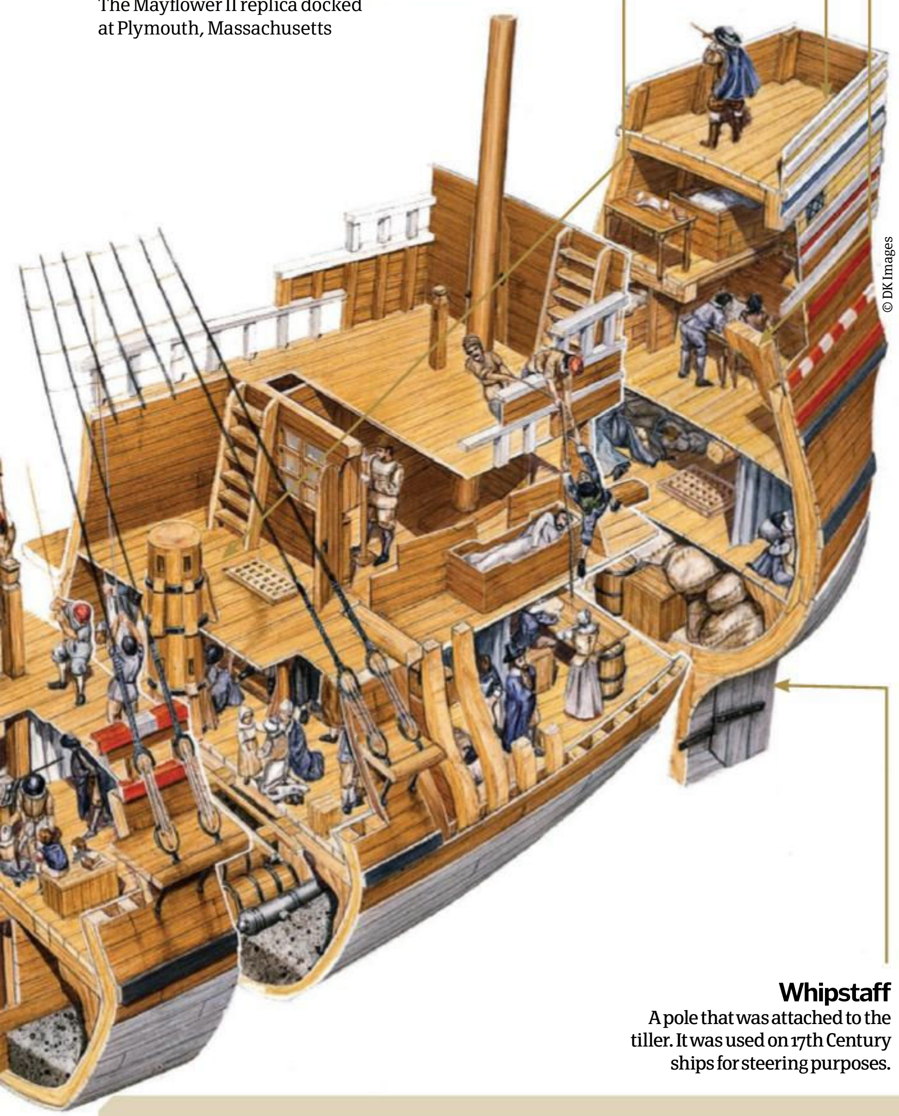


Beakhead
The beakhead is the protruding part of the foremost section of the ship.

Forecastle
Accommodation for the common sailors, the men slept here when not working on deck.

Hold
The hold is the deepest section of the ship. It was used to store cargo and accommodate passengers.

The Mayflower II replica docked at Plymouth, Massachusetts



ON THE MAP


The Mayflower arrived at the internal fish hook of Cape Cod

Pilgrim Fathers

In 1620 a group of puritans arrived on the Mayflower destined for the New World. They were known as the Pilgrim Fathers. The Pilgrim Fathers were disillusioned with the ungodly and hedonistic behaviour of their native Englishmen and believed that America was a land of opportunity where they could start a new religious community. They landed in a place that would come to be called New Plymouth, where they began to build houses, but it is believed that half their population died during the first year of occupation. The New World was seen as a dazzling land and a second Garden of Eden, but in reality the environment was harsh and unforgiving. Some natives were helpful and taught the settlers how to survive this wilderness, and in 1621 they produced their first successful harvest. This was celebrated with the first Thanksgiving – in turn, this became a traditional feast day – and it is still observed as an American national holiday.

HMS Victory

One of the most famous ships of all time, HMS Victory was instrumental in ensuring British naval supremacy during the late 18th and early 19th centuries

The only surviving warship to have fought in the American War of Independence, the French Revolutionary War and the Napoleonic wars, the HMS Victory is one of the most famous ships ever to be built. An imposing first rate ship of the line – line warfare is characterised by two lines of opposing vessels attempting to outmanoeuvre each other in order to bring their broadside cannons into best range and angle – the Victory was an oceanic behemoth, fitted with three massive gundecks, 104 multiple-ton cannons, a cavernous magazine and a crew of over 800. It was a vessel capable of blowing even the largest enemy vessels out of the water with magnificent ferocity and range, while also outrunning and outmanoeuvring other aggressors.

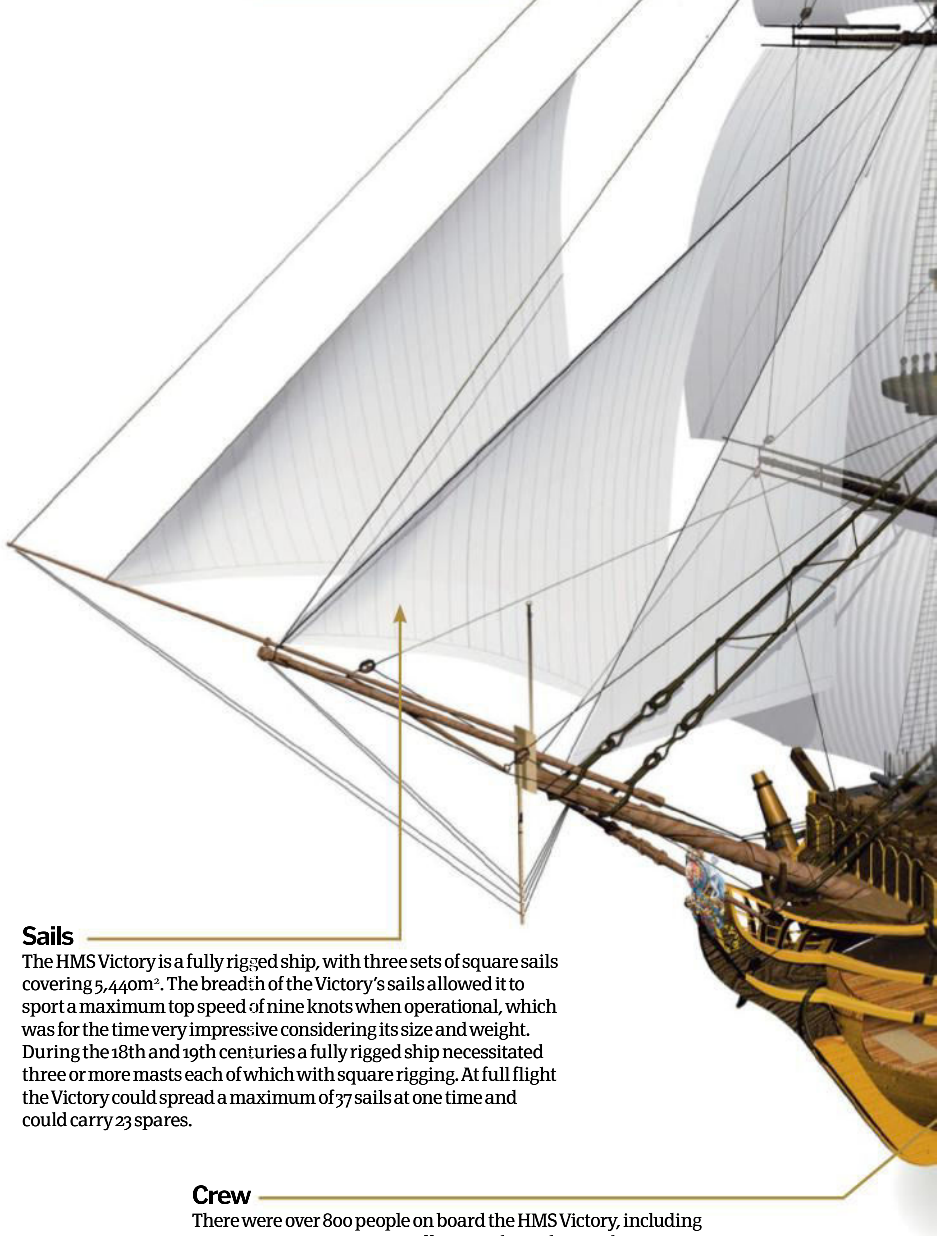
Historically, it was also to be Vice-Admiral Horatio Lord Nelson's flagship during the epic naval battle off the Cape of Trafalgar, where it partook in the last great line-based conflict of the age, one in which it helped to grant Nelson a decisive victory over the French and Spanish but at the cost of his own life.

Turner's famous painting of the Battle of Trafalgar in which the HMS Victory is shown in the midst of battle

The statistics...

HMS Victory

Class: First rate ship of the line
Displacement: 3,500 tons
Length: 227ft
Beam: 51ft
Draught: 28ft
Propulsion: Sails – 5,440m^2
Speed: 9 knots (17km/h)
Armament: 104 guns
Complement: 800



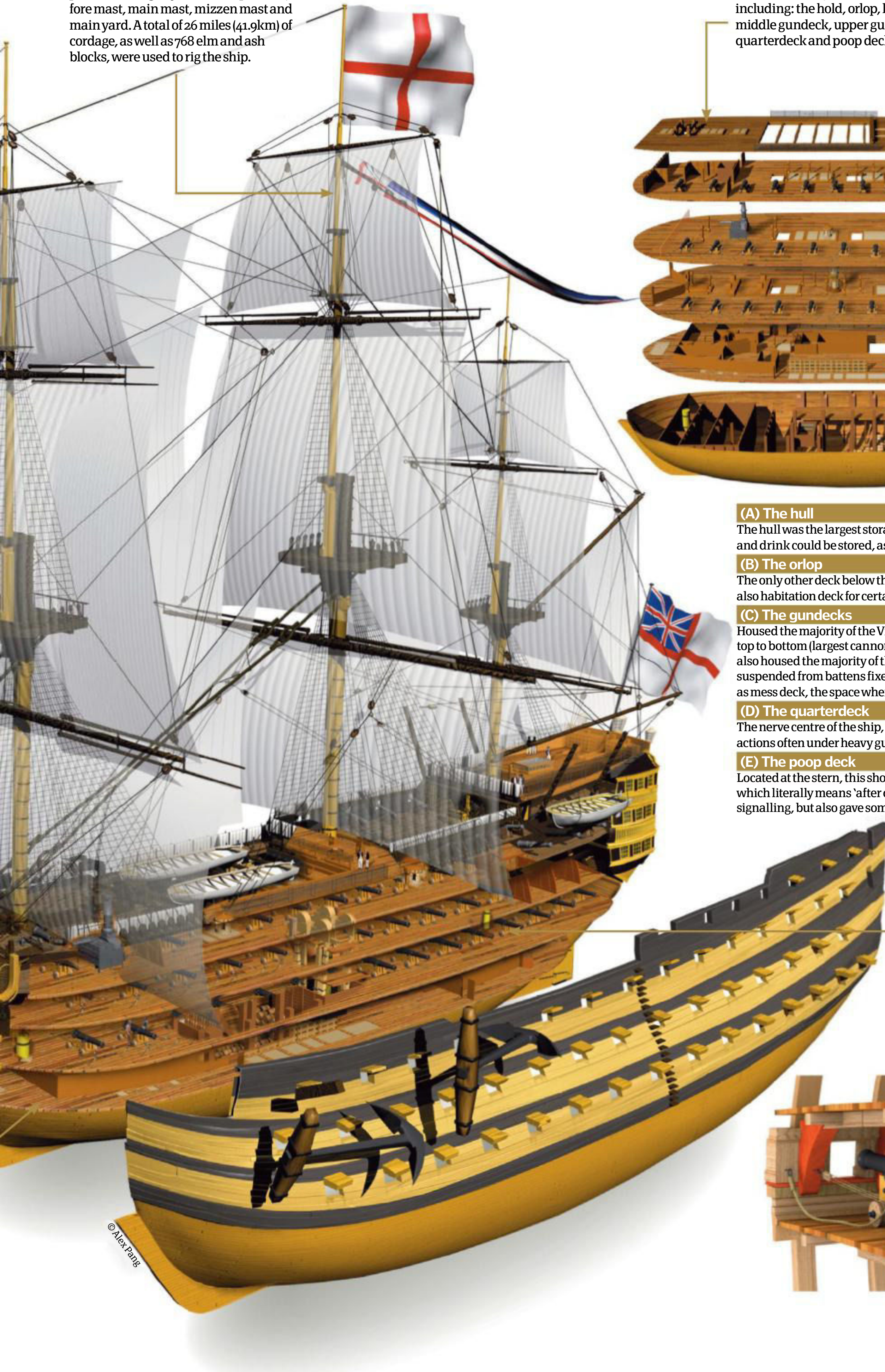
Sails
The HMS Victory is a fully rigged ship, with three sets of square sails covering 5,440m^2. The breadth of the Victory's sails allowed it to sport a maximum top speed of nine knots when operational, which was for the time very impressive considering its size and weight. During the 18th and 19th centuries a fully rigged ship necessitated three or more masts each of which with square rigging. At full flight the Victory could spread a maximum of 37 sails at one time and could carry 23 spares.

Crew
There were over 800 people on board the HMS Victory, including gunners, marines, warrant officers and powder monkeys among many others. Life on board was hard for the sailors, who were paid very little for their services and received poor food and little water. Disease was rife too, and punishments for drunkenness, fighting, desertion and mutiny ranged from flogging to hanging.

DID YOU KNOW? *HMS Victory cost £63,176 when finished in 1765, the equivalent of roughly £7 million today*

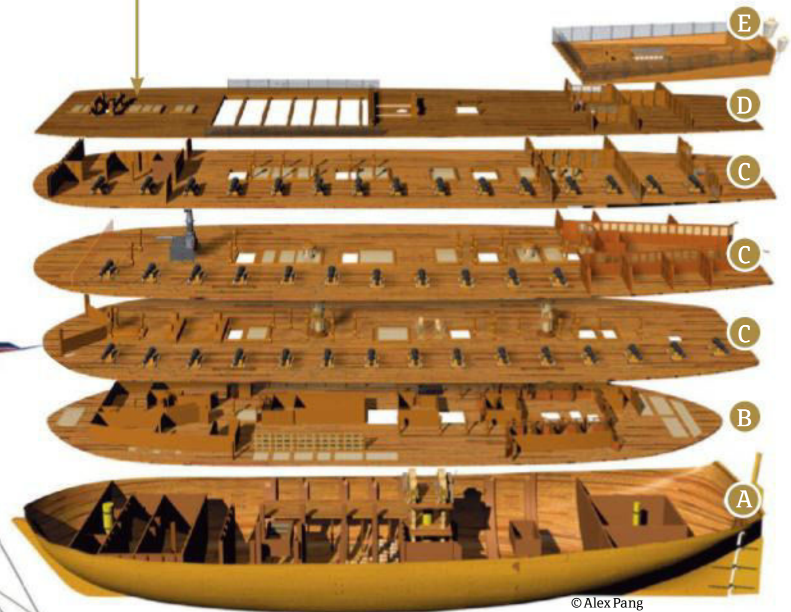
Masts

The HMS Victory sported a bowsprit (the pole extending beyond the ship's head), fore mast, main mast, mizzen mast and main yard. A total of 26 miles (41.9km) of cordage, as well as 768 elm and ash blocks, were used to rig the ship.



Decks

The HMS Victory had seven main decks, including: the hold, orlop, lower gundeck, middle gundeck, upper gundeck, quarterdeck and poop deck.



(A) The hull

The hull was the largest storage area on the ship where up to six months of food and drink could be stored, as well as any excess supplies.

(B) The orlop

The only other deck below the waterline, the orlop was another storage area and also habitation deck for certain crew members such as the purser.

(C) The gundecks

Housed the majority of the Victory's cannons, with a tiered arrangement from top to bottom (largest cannons on the bottom, smallest on the top). These decks also housed the majority of the crew and Royal Marines, sleeping in hammocks suspended from battens fixed to overhead beams. The lower gundeck also acted as mess deck, the space where the crew would live and eat.

(D) The quarterdeck

The nerve centre of the ship, where its commander dictated its manoeuvres and actions often under heavy gunfire from rival vessels.

(E) The poop deck

Located at the stern, this short deck takes its name from the Latin word puppis, which literally means 'after deck' or 'rear deck'. This deck was mainly used for signalling, but also gave some protection to the man helming the ship's wheel.

Cannons

As a first rate ship of the line, the Victory was a three-gundeck warship with over 100 guns. In fact, the Victory was fitted with 104 cannons: 30 x 2.75 ton long pattern 32-pounders on the gundeck, 28 x 2.5 ton long 12-pounders on the middle gundeck, 30 x 1.7 ton short 12-pounders on the upper gundeck, 12 x 1.7 ton short 12-pounders on the quarterdeck, and 2 x medium 12-pounders and 2 x 68-pounder carronades on the forecastle.

Cutty Sark

The world's last intact tea clipper trading ship, the Cutty Sark epitomised the tailend of the age of sail, built to negotiate cross-continent trading routes with great speed

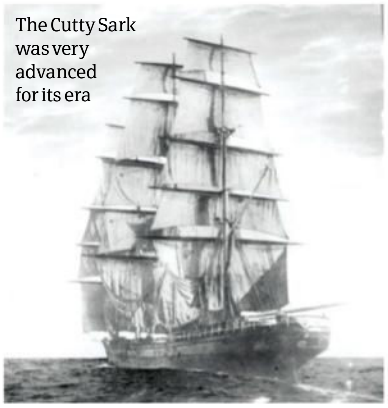
The Cutty Sark was an English clipper-class ship that was used predominantly to transport tea from China to England. It was built for speed, with a narrow hull, a wide, forward-raked bow and a square rig on a three-mast setup.

These factors enabled the ship to cut through rough waves with greater efficiency than pre-existing trading vessels, allowing produce such as tea, cocoa, coal and wool to be rapidly transported cross continent for expedited delivery (for the time). In fact, the high speeds attainable by clipper-class ships led to the formation of the 'Race of the Tea Clippers', an annual event where various crews battled it out to bring in the first tea shipment of the year.

The Cutty Sark was – and still is today, albeit as a tourist attraction – a prime example of the tea clipper. With planking, deadwoods, stem and sternpost made from American rock elm, a bespoke iron frame, a deck made from teak and solid brass bolting throughout, the ship was one of the most expensive and advanced clippers at sea. This build quality was ensured by its shipbuilder's determination to outsail the other great clipper of the age the Thermopylae, something that it would proceed to do no less than five times during its career. Luckily, despite the ship falling into poor condition, numerous refits and restorations mean that today its condition remains unchallenged worldwide.

Unfortunately, as with many tools and technologies, the age of the Cutty Sark/clipper was not to last. The invention of the steam engine had led to increasing mechanisation throughout the Industrial Revolution and by the late-19th Century steam-powered ships were becoming financially viable to the mass-market. This, in partnership with the opening of the Suez Canal – which created a shortcut between Europe and Asia not traversable by sail-powered ships – caused clippers to be slowly phased out. As such the Cutty Sark was sold in 1895 and re-rigged in Cape Town, South Africa, returning to England in the Twenties to serve as a training ship.

Today the Cutty Sark is preserved in a dry dock in Greenwich, London, where it is viewable to the public as a maritime museum piece.


The Cutty Sark was very advanced for its era


The Cutty Sark moored in Sydney Harbour, Australia

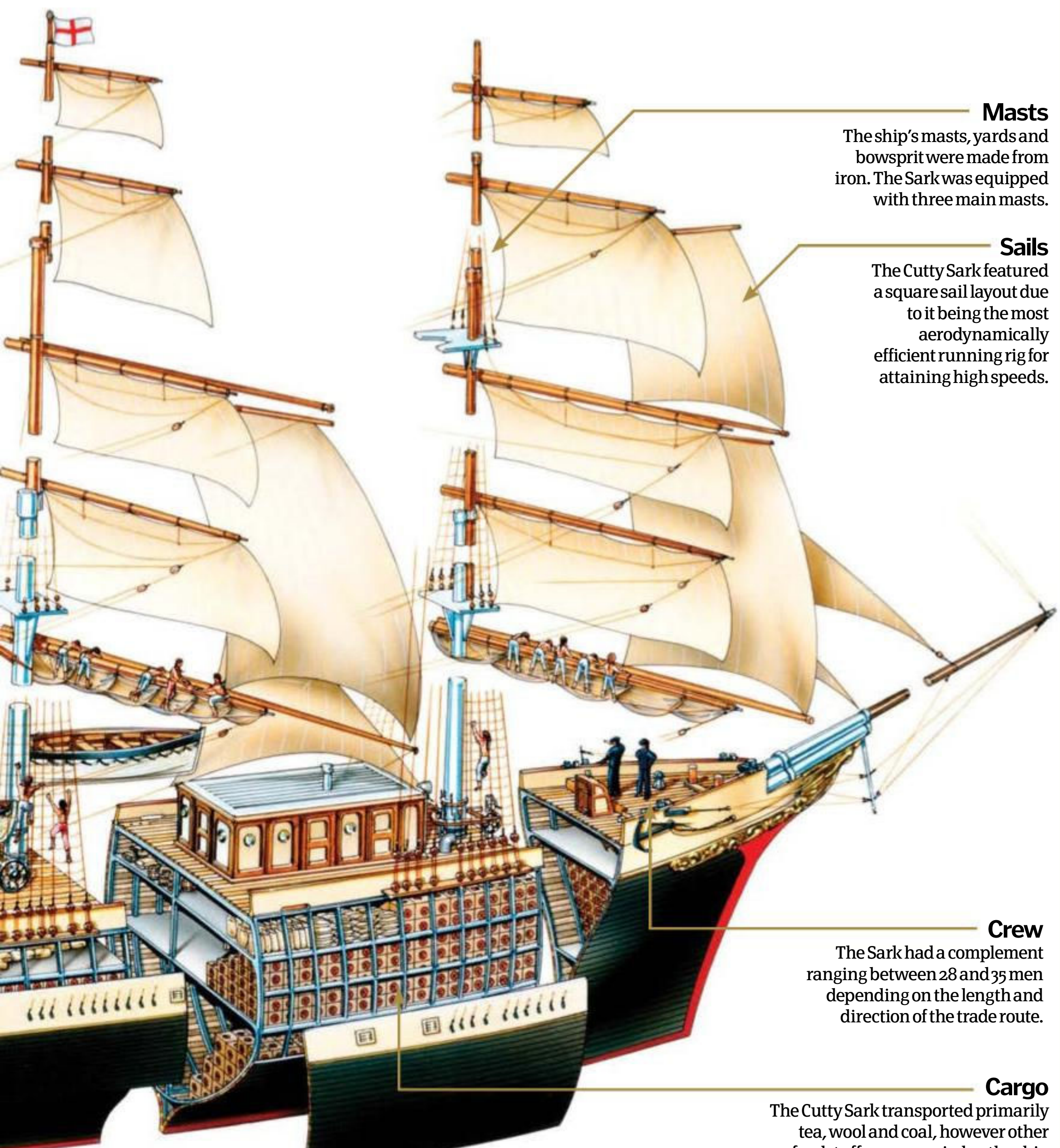
Hull
The Sark's hull was made from wood on a metal frame. The ship's deck and brims were made from teak.

The statistics…

Cutty Sark

Class: Clipper
Tonnage: 975 GRT
Displacement: 2,100 tons
Length: 85m (279ft)
Beam: 11m (36ft)
Max speed: 32km/h (17kn)
Capacity: 1,700 tons
Complement: 28-35

The Cutty Sark in service during 1869. Today, the ship is one of only three left from the 19th Century



Time waits for no clipper

There are only two other 19th-Century clippers still around, though they are fast decaying

© David Cook

City of Adelaide

Built: 1864
Fate: Sunk/salvaged
Position: Irvine, Scotland

Designed to transport passengers and merchandise between England and Australia during the latter's colonisation, the City of Adelaide is today the oldest surviving clipper in existence. During its heyday the Adelaide made 23 annual return voyages to South Australia and, consequently, it is estimated that 250,000 modern-day Australians can trace their lineage to a passenger on the ship. The ship was accidentally sunk while in Prince's Dock, Glasgow, in 1991 and, while salvaged in 1992, is now a severely dilapidated wreck. As with the Cutty Sark, the Adelaide is an A-listed protected structure.

© Google/André Bonacin

Ambassador

Built: 1869
Fate: Beached
Position: Estancia San Gregorio, Chile

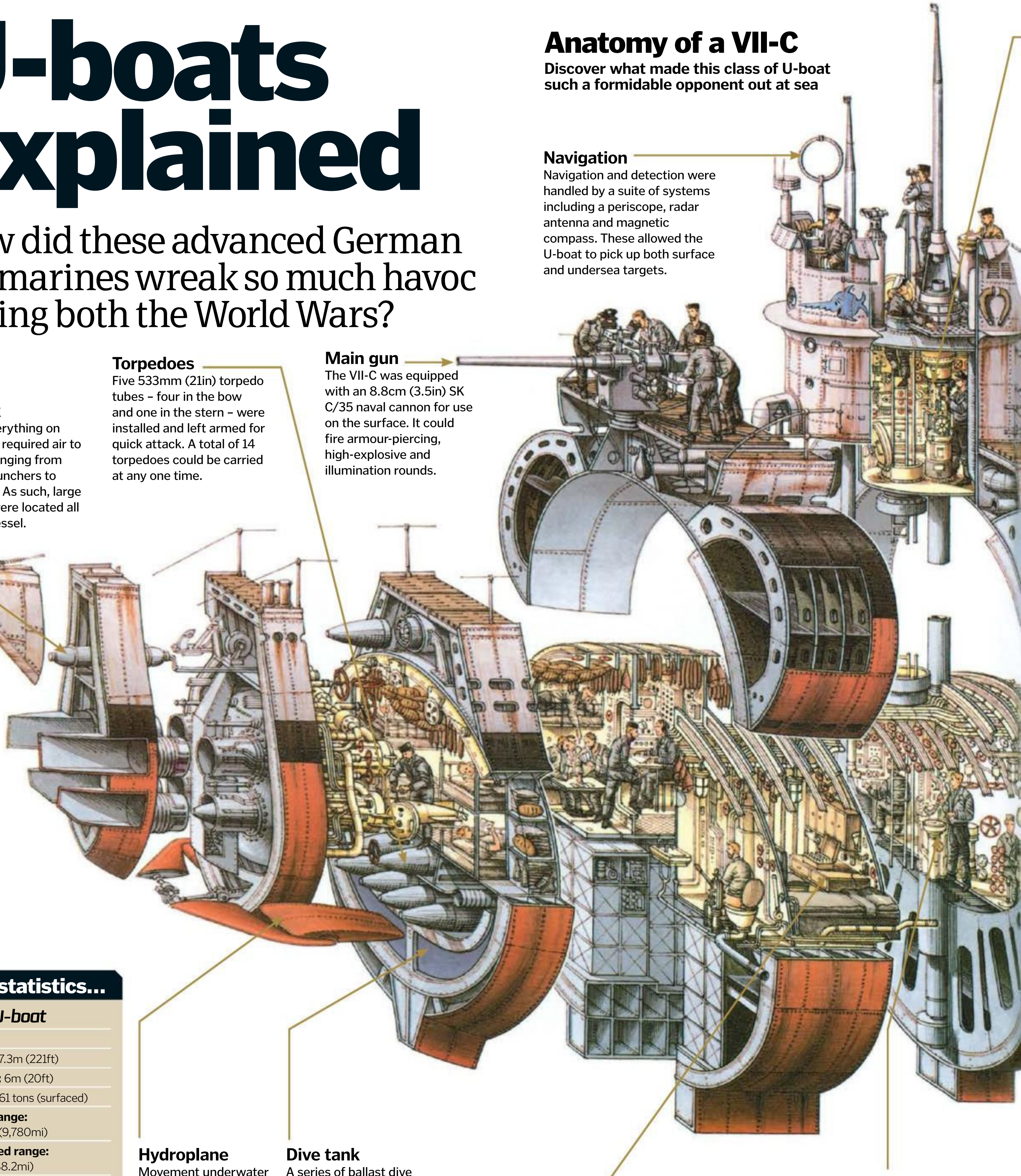
Built in the Lavender Dry Dock on the River Thames during 1869, the Ambassador was designed to transport tea from China to England. A frequent contestant in the great tea races of the day, the Ambassador was one of the fastest clipper ships, with a personal-best time of 108 days to complete the journey. After its tea-trading days, the Ambassador was used to transport wool and other products around the world. Unfortunately, in 1899, the ship was in a state of disrepair, with its then owner unable to pay for its restoration. As a result, it was beached in Estancia San Gregorio, Chile, where it remains to this day.

U-boats explained

How did these advanced German submarines wreak so much havoc during both the World Wars?

Anatomy of a VII-C

Discover what made this class of U-boat such a formidable opponent out at sea



Navigation
Navigation and detection were handled by a suite of systems including a periscope, radar antenna and magnetic compass. These allowed the U-boat to pick up both surface and undersea targets.

Air tank
Almost everything on the U-boat required air to operate, ranging from torpedo launchers to dive tanks. As such, large air tanks were located all over the vessel.

Torpedoes
Five 533mm (21in) torpedo tubes – four in the bow and one in the stern – were installed and left armed for quick attack. A total of 14 torpedoes could be carried at any one time.

Main gun
The VII-C was equipped with an 8.8cm (3.5in) SK C/35 naval cannon for use on the surface. It could fire armour-piercing, high-explosive and illumination rounds.

Hydroplane
Movement underwater was controlled with a series of hydroplanes – short, wing-like appendages that could be angled as desired. Facing them up caused the vessel to dive.

Dive tank
A series of ballast dive tanks were located at the lower front of the vessel. When on the surface these tanks were empty and filled with air; to submerge, they were flooded with water.

Signal station
Even when submerged up to 9m (30ft) the U-boat could still send and receive long-wave radio signals. Codes were encrypted prior to transmission.

Control room
When submerged, the centre of operations was the control room. Steering, navigation and fire commands were all issued from here.

The statistics...

VII-C U-boat

Crew: 44
Length: 67.3m (221ft)
Diameter: 6m (20ft)
Weight: 761 tons (surfaced)
Surface range: 15,739km (9,780mi)
Submerged range: 141.9km (88.2mi)
Max surface speed: 30.5km/h (19mph)
Max submerged speed: 13.5km/h (8.4mph)
Armament: 14 torpedoes; 60 mines; 8.8cm (3.5in) main gun

Conning tower
Each VII-C was topped with a conning tower at the centre of the vessel. The commander of the U-boat controlled the submarine from here when surfaced.

Flak cannon
A few VII-Cs were fitted with a flak cannon too. These 20mm (0.8in) guns were used to fire at any enemy attack aircraft trying to blow the U-boat out the water.

Storage
There was no dedicated storage area in U-boats due to their compact, narrow design. As such meat, bread and other produce were kept in the crew quarters.

U-boats – or 'unterseeboots', which translates as 'undersea boats' – were a series of submarines used in both World War I and World War II. They were famed for their ability to stealthily strike at Allied vessels, ganging up on them in brutally efficient 'wolf packs' to inflict the maximum damage. In World War I alone, 430 Allied and neutral ships were sunk by these roving packs.

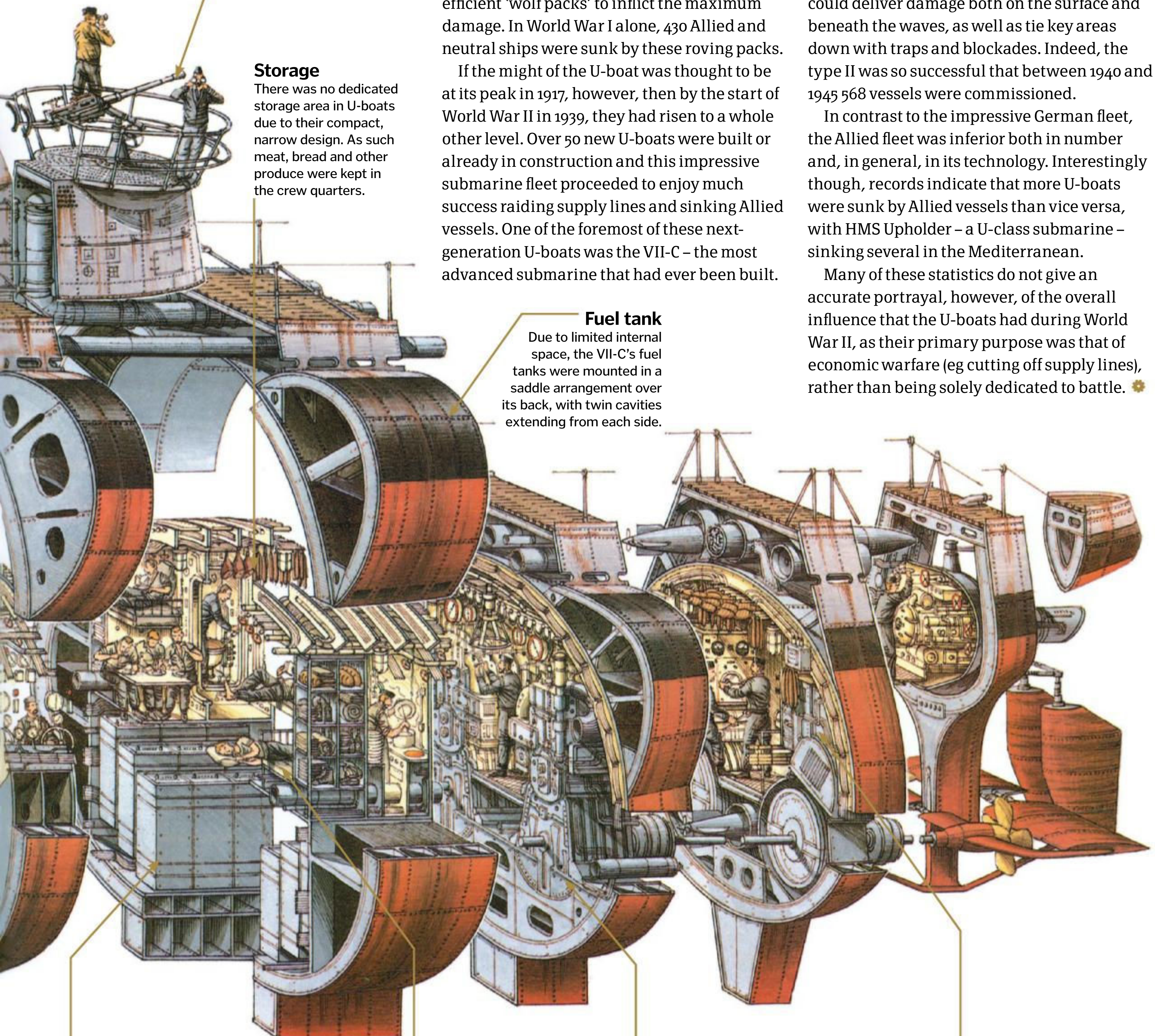
If the might of the U-boat was thought to be at its peak in 1917, however, then by the start of World War II in 1939, they had risen to a whole other level. Over 50 new U-boats were built or already in construction and this impressive submarine fleet proceeded to enjoy much success raiding supply lines and sinking Allied vessels. One of the foremost of these next-generation U-boats was the VII-C – the most advanced submarine that had ever been built.

Capable of travelling thousands of miles on the water and then able to submerge and strike enemy targets within a 142-kilometre (88-mile) range, the VII-C was the backbone of Germany's submarine fleet. Armed with a bounty of torpedoes, sea mines and cannons, the VII-C could deliver damage both on the surface and beneath the waves, as well as tie key areas down with traps and blockades. Indeed, the type II was so successful that between 1940 and 1945 568 vessels were commissioned.

In contrast to the impressive German fleet, the Allied fleet was inferior both in number and, in general, in its technology. Interestingly though, records indicate that more U-boats were sunk by Allied vessels than vice versa, with HMS Upholder – a U-class submarine – sinking several in the Mediterranean.

Many of these statistics do not give an accurate portrayal, however, of the overall influence that the U-boats had during World War II, as their primary purpose was that of economic warfare (eg cutting off supply lines), rather than being solely dedicated to battle.

Fuel tank
Due to limited internal space, the VII-C's fuel tanks were mounted in a saddle arrangement over its back, with twin cavities extending from each side.



Battery array
Huge banks of electrical batteries were located in the lower centre portion of the U-boat. These supplied energy for the motors and lights.

Crew quarters
Living quarters were situated throughout the vessel. Up to 44 people could be accommodated, with individuals sleeping on narrow, wall-mounted bunk beds.

Engine
When on the surface, the U-boat was propelled by two supercharged six-cylinder, four-stroke M6V 40/46 diesel engines. These generated a maximum 2,400kW (3,200hp).

Motors
While submerged the U-boat was propelled by a brace of electric motors that produced 560kW (750hp). These were needed as the diesel engines required air to operate.

Bathyscaphe Trieste

A real-life Nautilus, the Bathyscaphe Trieste explored the deepest parts of Earth's oceans, remaining to this day one of the only manned vehicles to have reached the bottom of the Mariana Trench in the Pacific

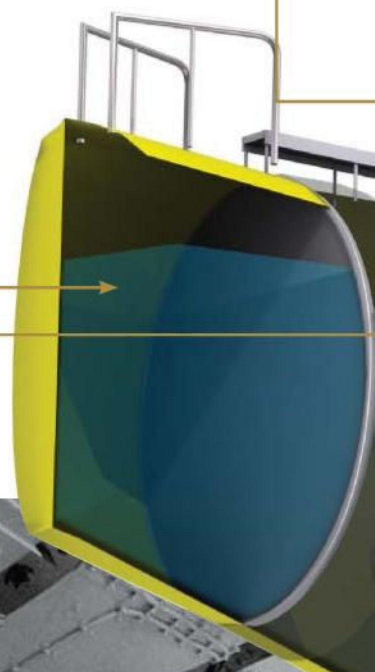
After passing 9,000 metres (30,000 feet), one of the Plexiglas windows cracked. Over 1,000 atmospheres – a pressure over six tons per square inch – relentlessly bore down upon the Bathyscaphe Trieste. The hull shook violently, threatening to collapse under the mighty strain. If fractured on even a microscopic scale, the weight of the Earth's deepest ocean would rip the vessel in two, triggering explosive decompression and instantly killing both oceanographer Jacques Piccard and pilot Lieutenant Don Walsh of the US Navy. 23 January 1960, however, was not their day to die. The men had still not reached the bottom of the Mariana Trench's Challenger Deep; the structure *had* to hold – there was no plan B.

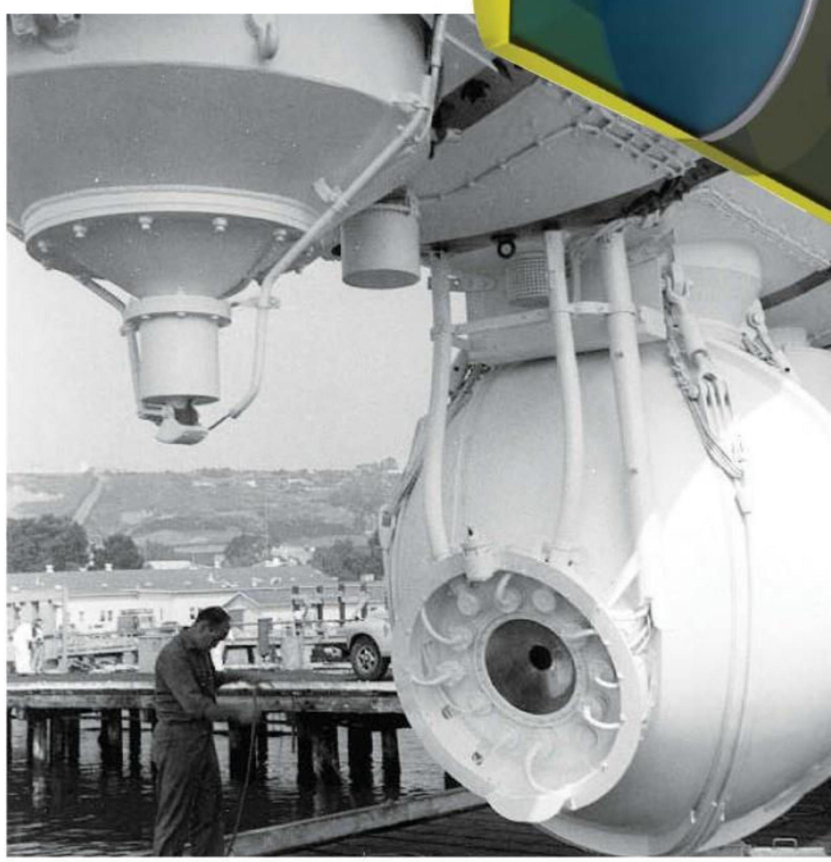
Descending further into the black void, completely cut off from the outside world – the sonar/hydrophone communications system had packed up hours ago – the Trieste continued to dump iron pellets into its ballast system. After all, you don't descend vertically nine kilometres (nearly six miles) beneath the surface of the ocean only to quit so close to your goal. Then finally, out of nowhere and after four hours and 48 minutes within a two-metre (seven-foot) pressurised sphere, Piccard, Walsh and the Trieste touched down. Clouds of diatomaceous ooze (made of the skeletons of dead sea-creatures) diffused from the seabed on contact, filling the surrounding water with a liquidated organic haze.

Half an hour later, after periodically observing this alien environment with high-powered quartz arc-light lamps – periodically as when activated they caused the water to violently boil – and discovering a multitude of life including a white flatfish, several shrimp and jellyfish, Piccard initiated the Trieste's ascent. The vessel had held, but at a depth of 10,916 metres (35,814 feet) the temperature of the pressure sphere was dropping continuously (the minimum recorded was just seven degrees Celsius/45 degrees Fahrenheit); if they were not careful, there would be no return. Three hours and 15 minutes later, the Trieste re-emerged into the daylight and human civilisation. The vessel and its crew had been to a world only envisioned in fiction and returned with field-changing information.

Key to the data gathered was establishing the existence of life at the bottom of Earth's deepest ocean. This revealed that not only were there creatures impervious to extreme atmospheric pressures, but also that water at this depth wasn't stagnant. This was a clear indication that ocean currents even penetrated these extreme depths, so they should not be used as a dumping ground for radioactive waste. Unfortunately, despite this first-hand evidence, dumping of this kind still continues throughout large parts of the world to this day.

Today the legacy of the Trieste is being built upon, with numerous programmes currently underway focused on designing new vehicles to return to this uncharted territory. The most high profile of these is Richard Branson's Virgin Oceanic, which intends to return to the bottom of the Mariana Trench in the near future.

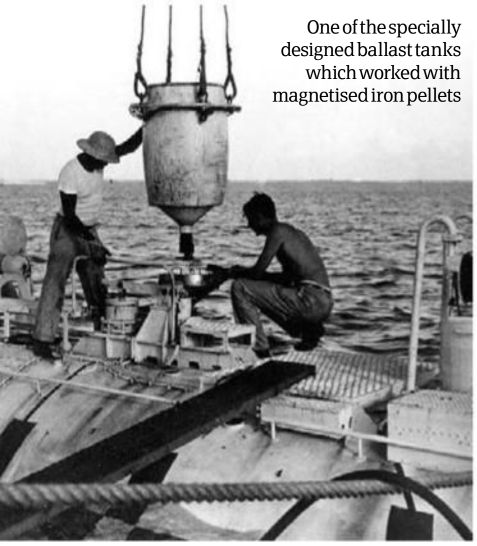




A close-up view of the Trieste's pressure sphere, clearly showing the Plexiglas observation window and instrument leads

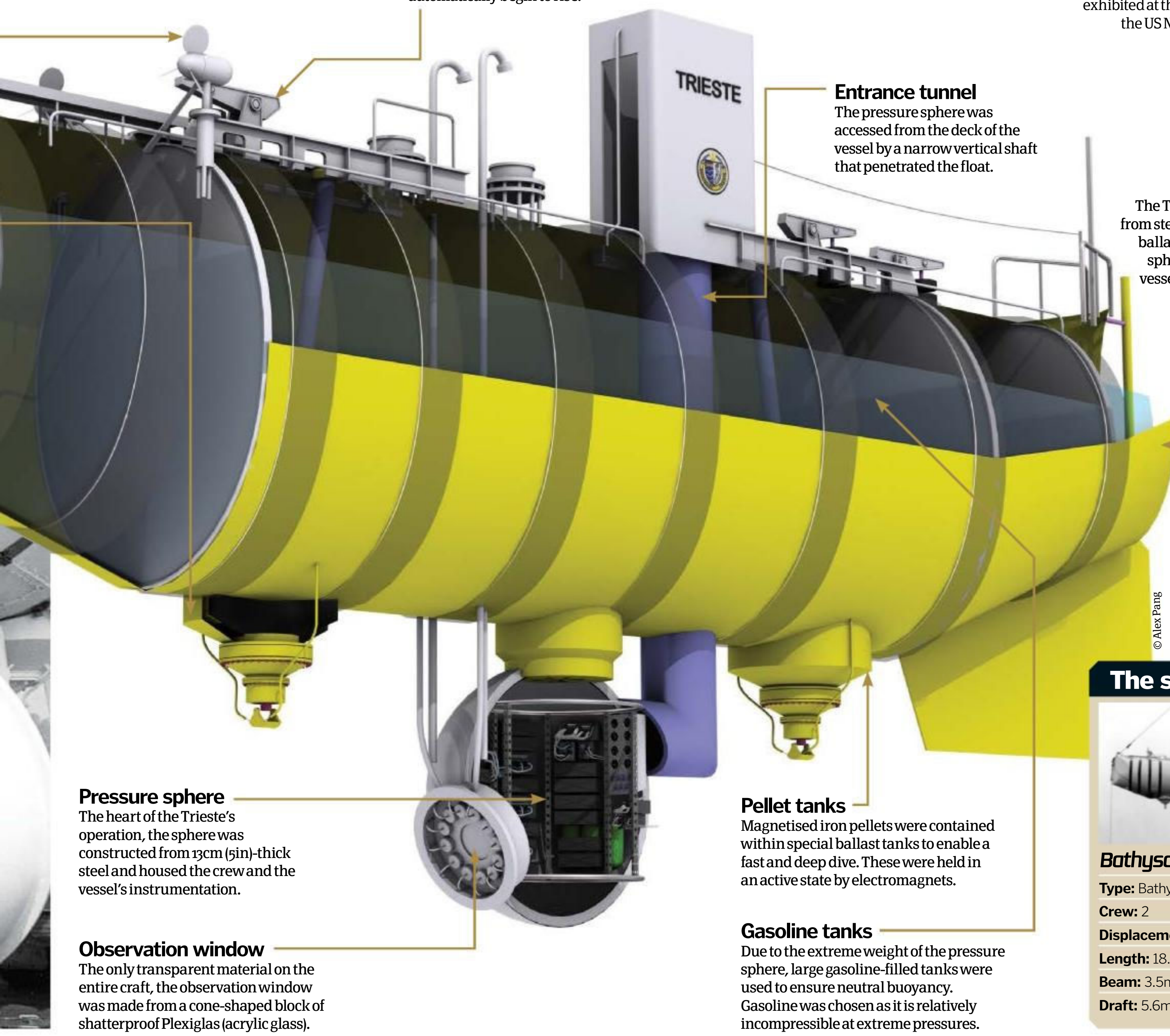
Inside the Bathyscaphe Trieste

We take a look at the machinery and technology that enabled this record-breaking dive



One of the specially designed ballast tanks which worked with magnetised iron pellets

The Bathyscaphe Trieste is now exhibited at the National Museum of the US Navy in Washington DC



© Alex Pang

Electromagnets

The magnetic iron pellets that allowed the Trieste to descend so deep were held in place actively by large electromagnets. As such, if there was an electrical failure, the vessel would automatically begin to rise.

Entrance tunnel

The pressure sphere was accessed from the deck of the vessel by a narrow vertical shaft that penetrated the float.

Hull

The Trieste's hull was made from steel and held numerous ballast tanks. The pressure sphere that contained the vessel's crew was mounted centrally to its belly.

Pressure sphere

The heart of the Trieste's operation, the sphere was constructed from 13cm (5in)-thick steel and housed the crew and the vessel's instrumentation.

Observation window

The only transparent material on the entire craft, the observation window was made from a cone-shaped block of shatterproof Plexiglas (acrylic glass).

Pellet tanks

Magnetised iron pellets were contained within special ballast tanks to enable a fast and deep dive. These were held in an active state by electromagnets.

Gasoline tanks

Due to the extreme weight of the pressure sphere, large gasoline-filled tanks were used to ensure neutral buoyancy. Gasoline was chosen as it is relatively incompressible at extreme pressures.

The statistics…

Bathyscaphe Trieste

Type: Bathyscaphe

Crew: 2

Displacement: 51 tons

Length: 18.1m (59.6ft)

Beam: 3.5m (11.6ft)

Draft: 5.6m (18.6ft)

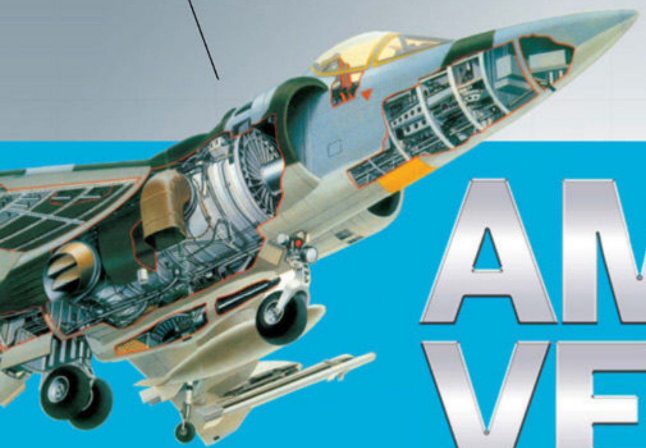
HOW IT WORKS

BOOK OF

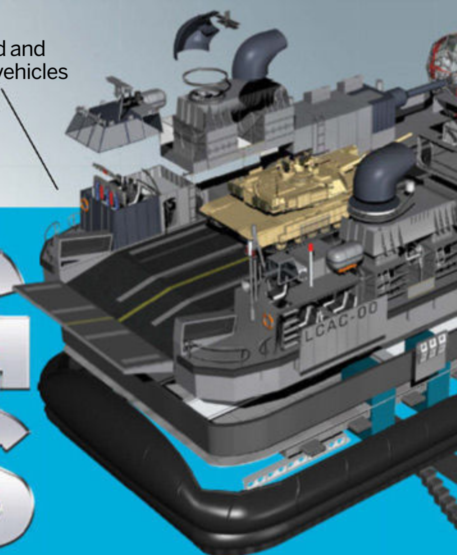
AMAZING VEHICLES

A LOOK INSIDE SOME OF THE WORLD'S MOST INCREDIBLE MACHINES

Military fighter jets



Land and water vehicles



LAND

See how technological advances made our cars, bikes and trains faster and more energy efficient than ever

AIR

Take to the skies and discover some of the incredible aircraft that are faster, better and stronger

SEA

Learn about the amazing vessels that master the seven seas and dive the depths of the oceans

The fastest, most eco-friendy cars

Deep sea explorers

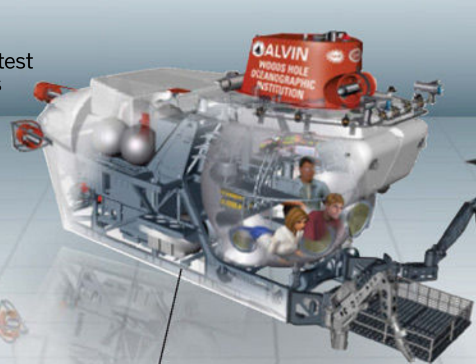
MILITARY

Find out how new methods and materials are changing the face of battle with these machines

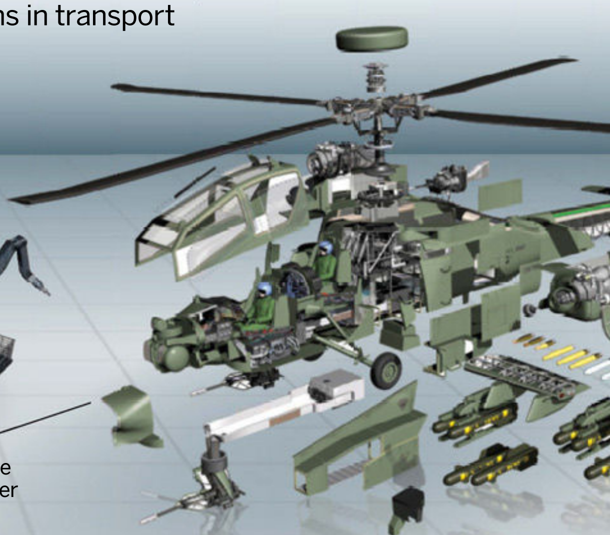
HISTORIC

From The Mayflower to the Model T Ford, uncover some of the most iconic innovations in transport

World's fastest vehicles



The most advanced machinery



The power of the Apache helicopter